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OF WESTERN SAMOA SOILS.

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ANALYSIS AND PREDICTION OF THE PROPERTIES OF WESTERN SAMOA SOILS

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IN
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By
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ABSTRACT

The object of this study was to develop statistical procedures to reduce the time and cost of reconnaissance soil surveys. A detailed study of the nature, genesis, and classification of Western Samoa soils provided a basis for interpretation of statistical results.

Age of parent material and the amount and distribution of rainfall had the greatest influence on soil formation. Soils derived on the youngest volcanic material were higher in organic matter, cation exchange capacity, and base saturation and lower in free iron oxides than those derived from older volcanics. As the age of the soil increased, the mineralogy changed from mixed-layer and amorphous materials to predominately hydrated iron and aluminum oxides. Soils occurring on the steep eroded slopes of the oldest volcanics were halloysitic.

Soils with pronounced dry periods in the lowest rainfall areas showed weak mixed-layer mineral development. With increasing rainfall, amorphous materials, hydrated iron and aluminum oxides and depth of solum increased; base saturation and boulderness decreased.

The soils, except for an Oxisol and a possible Ultisol, were Inceptisols. Dystropepts and Humitropepts were the predominant Great Groups.

Summary statistics indicated that a majority of the variables had positively skewed distributions. A normal density function represented pH; lognormal density functions represented percent organic C, percent total N, and exchangeable K; gamma density functions represented cation exchange capacity, total bases, C/N ratio, and exchangeable Ca and Mg. The use of the density functions provided estimates of central tendency and defined a modal profile.

Correlation and regression analyses separated the variables into two groups: Those affected by rainfall - base saturation, total bases, exchangeable Ca and Mg; and those affected by age - percent organic carbon, percent total N, cation exchange capacity, and exchangeable K. Prediction of selected variables of a control group of soils indicated that the regression equations were accurate over a wide range of conditions.

Regional trends of soil variables were examined by trend surface analysis. Linear, quadratic, and cubic polynomial surfaces were fitted by least squares to an array of data points. The resulting "best" surface was contoured and plotted by means of a computer. Surfaces for base saturation, total bases, exchangeable Ca and Mg were identical to rainfall (MAR) maps. Percent organic carbon, percent total N, cation exchange capacity, and exchangeable K had lower R^2 values than the above surfaces. Examination of the residual surfaces indicated that the deviations were associated with local effects of parent material. Surfaces for climatic and topographic variables were fitted. All the various surfaces were screened by means of a computer to produce predicted special purpose soil maps.

Soil variability between and within the different levels of classification was estimated by nested analysis of variance design with use of the U. S. Comprehensive Soil Classification system as a frame of reference. The results indicated that variability of some properties could be estimated. Variability of other properties, however, could be estimated only with difficulty due to the vertical anisotropy of soils and the criteria used in the classification system.

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INTRODUCTION

Reconnaissance soil surveys generally have a low information content in consideration of the time and cost of making these surveys. It is desirable and possible to increase the information derived from existing reconnaissance soil surveys and to decrease the number of samples needed in future surveys to provide reliable estimates of soil properties. Statistical analyses and automatic data processing equipment are the means for obtaining these objectives.

Two reasons for the selection of Western Samoa as the study area were (1) the existence of a completed reconnaissance soil survey of Western Samoa and (2) the typicality of Western Samoa to many high islands of the Pacific in providing arrays of climatic zones and ages of parent material. The second reason, the systematic patterns of the dominant genetic factors, greatly simplified the statistical models. Because there are more similarities between the high islands of the Pacific than there are differences, this study dealt with providing general statistical procedures and models for maximizing the information content of future reconnaissance soil surveys of other high islands, particularly those occurring in Micronesia.

LITERATURE REVIEW

Past Research on the Nature and Properties of Western Samoa Soils

Hamilton and Grange (1938) and Seelye et al. (1938) made the first systematic study of the nature of Western Samoa soils. On Upolu, they examined a sequence of soils from near sea level at Saleimoa to 2,000 feet elevation at the Tiavi Saddle. They separated the soils in the field on the basis of (1) relative age of the lava flows and (2) rainfall zones.

They noted that all the soils were laterites and were generally infertile. All the soils studied contained unusually high amounts of nitrogen. Chemical analyses of the soils supported their field separation of the soil series. Silicon, calcium, magnesium, and sodium leached rapidly from the soil profiles while aluminum, iron, and titanium increased. Soils of the high rainfall areas (Tiavi) were as low in silica as the laterites of India. The silica sesquioxide ratio of the soils in the sequence ranged from 0.63 to 0.04. One unusual phenomenon that Seelye et al. noted was that "the lateritic process has gone far without the segregation of iron oxides and alumina."

In 1959, Wright (1963) made a reconnaissance soil survey of Western Samoa. He delineated 90 mapping units of soils, 55 of these units having been formed from olivine basalts. In studying the soils, Wright considered the composition, form, and age of the basic volcanic rock and climatic patterns.

The composition of volcanic rock influences the nature of the soils in the Fagaloa volcanics. These soils are firmer, stickier, and more plastic than soils formed on the younger basalts. Wright reasoned that these differences were caused by the andesitic nature of the Fagaloa volcanics, which when weathered, formed clays of mostly kaolin and hydrated iron oxides. Another differentiating characteristic of these soils is the high amounts of exchangeable magnesium. The Ca/Mg ratio is about one compared to the usual value of two to four.

Another important factor in Western Samoa soils is the form of parent material. Soils developed from aa lava are usually weathered and are deeper than soils developed from pahoehoe in similar climatic zones. The highest weathering rate occurs in soils developed from scoria. The soils developed from ash and scoria are redder and have more kaolin than soils developed from aa.

Wright found that age differences, particularly with pahoehoe, are another important factor. The youngest lava flows have only a thin mantle of soil mixed with humus. The base status of these soils is high and their textures vary from sand to loam. As the flows become progressively older, base saturation of the resulting soils decreases, texture tends toward a clay, and the color changes from dark grey-brown to dark reddish-brown.

Climate also has a pronounced effect. Soils in the uplands and lowlands show consistant differences irrespective of age. With increasing rainfall, soil depth increases, soil colors generally range from dark reddish brown to yellowish brown, and base saturation decreases. The mineralogical changes are predominantly gibbsite in the lowlands to kaolin in the foothills to allophane in the uplands. Wright attributed this mineralogical change to decreased weathering caused by lower temperatures. He concluded that changes in the weathering pattern are affected more by changes in temperature than by changes in rainfall.

In his soil survey Wright regarded all Samoan soils derived from basalt as latosolic soils. The only exception was soils developed on lava extruded after 1760. These he considered lithosols. He subdivided Western Samoa soils according to (1) type of basaltic parent material (major soil suite), (2) age of the parent material (minor soil suite), (3) form of the parent material (soil micro-suite), and (4) climatic zones (soil series).

Factors Affecting Soil Formation

In his study of parent rock to clay mineral alteration in Hawaii, Bates (1960a, 1960b) identified six factors that he considered most influencial on the weathering process. These factors were the geological parameters of age, composition, and texture of the rock, climatic factors of rainfall and temperature, and the topographic factor of slope and its influence on drainage.

Sherman and Ikawa (1968) suggest that soil formation in Hawaii is the product of two actions, weathering and leaching. They define weathering as the process of mineral decomposition and leaching as the solution and removal of ionic components of minerals. Governing weathering are the environmental and time "intensity" factors and the resistance "capacity" factors of the parent rock.

Age

Bates (1960a) and Sherman and Ikawa (1968) gave only a cursory example of the effect of age. Using the extent of gibbsite as a criterion of age, Bates noted that gibbsite found in soil decreased from Kauai (oldest Island) to Oahu, Molokai, and Maui (intermediate age) to Hawaii (youngest). He also generalized that in the Hawaiian Islands age may override differences caused by composition and texture but not differences caused by rainfall or slope. Sherman and Ikawa (1968a) compared two Lahaina profiles on Kauai and Maui. The main differences between these two sites were that the Kauai soil had lost more silica, calcium, and magnesium and gained more titanium and iron oxides than the younger Maui soil.

Composition

Both Sherman and Ikawa (1968) and Bates (1960a) noted that rocks decompose at a rate determined by the surface nature of the minerals in the rock, and by the resistance of these minerals to chemical solution. The amounts of ionic components in the parent rock are another important factor in composition (Bates, 1960a). The amounts of silica, magnesium, and calcium that have not been leached govern intermediate products of weathering. The original amounts of iron, aluminum, and titanium govern the end products of weathering.

Texture and Form

Rock texture and form of volcanic material govern the rate of leaching by percolating waters. Ash, being porous, weathers rapidly. The glassy crust of pahoehoe, acting as a sealer, retards leaching through the underlying rock. When this glassy crust does weather, the underlying rock, usually porous, weathers rapidly. Aa lava has large macropores, but the matrix is dense and has a low porosity resulting in slower weathering than ash.

Rainfall and Temperature

Since weathering in tropical and subtropical areas is largely chemical, the amount and distribution of rainfall are important. Sherman, Walker and Ikawa (1960) proposed a sequence of soils based on the amount and distribution of rainfall for Hawaii. He contends that under semiarid conditions montmorillonite would be the first mineral formed. With continued base removal and with prolonged dry seasons, kaolin clays would develop and become predominant. Kaolin increases with rainfall to 30"/year then decreases. Under moderate or heavy rainfall with definite dry and wet seasons iron and titanium oxides would increase. In continually moist conditions (good drainage) aluminum oxide would be the stable constituent. Gardiner (1967) found that free iron oxides, illite, quartz, and gibbsite increase with increasing rainfall.

Bates (1960a) commented that temperature had very little effect on soil weathering in Hawaii. Atkinson (1969) found that the organic matter content of soils developed on recent lava flows generally decreased with increasing temperature. He also found that rainfall greatly influenced this organic matter content.

Slope

The slope factor causes local variability in leaching and erosion. Areas with gentle slopes and high permeability of rocks have very little runoff, greater leaching, and therefore, deep weathering. Areas with steep slopes have more runoff, less leaching, and are usually less weathered. Runoff in areas having steep slopes and unstable soil produces another effect on soil formation, the removal of the intermediate and end products of weathering. This erosional process exposing fresh material begins a new cycle of soil formation (Bates, 1960a).

DESCRIPTION OF THE STUDY AREA

Location

The Samoan Archipelago lies between latitudes 13° and 15°S and longitudes 169° and 173°W near the center of the Pacific Ocean, Western Samoa, not American (Eastern) Samoa, includes the two major islands of Upolu and Savai'i and two smaller islands, Apolima and Manono. This study included only the major islands.

Landform

Savai'i, the larger of the major islands with 730 square miles, is 47 miles long and has a maximum width of 27 miles. Elevation of the central ridge is 6,100 feet. Upolu with 430 square miles is also 47 miles long but has a maximum width of 16 miles. Elevation of the central ridge is 4,000 feet.

Relatively young lavas, producing nearly smooth and undisected surface features, cover most of the land area of Western Samoa. Covering the remaining land area, tall remnants of old flows produce a monadnock-like appearance. Reefs, covered by lavas, form the gently sloping land surfaces of the lower elevations. Further inland toward the rift zone the slope becomes steep.

Wright (1963) divides the landform of Upolu and Savai'i into four topographic regions. The first is the lowland region containing undulating and gently rolling slopes of 3.5 to nine percent extending from sea level to 750 feet. The second region, the foothills, contains rolling and strongly sloping land ranging from nine to 27 percent. Wright contends that the series of steps in this area constitutes ends of lava flows or small fault scarps. The third topographic region is the upland region, a plateau which occurs at 2,000 feet on Upolu and eastern Savai'i and at 4,000 feet on central Savai'i. The upland region has undulating to rolling relief and contains numerous extinct cinder cones. The last region, the highland, occurs only on Savai'i. It contains clusters of volcanic cones in the center of the upland plateau which has a maximum elevation of slightly over 6,000 feet.

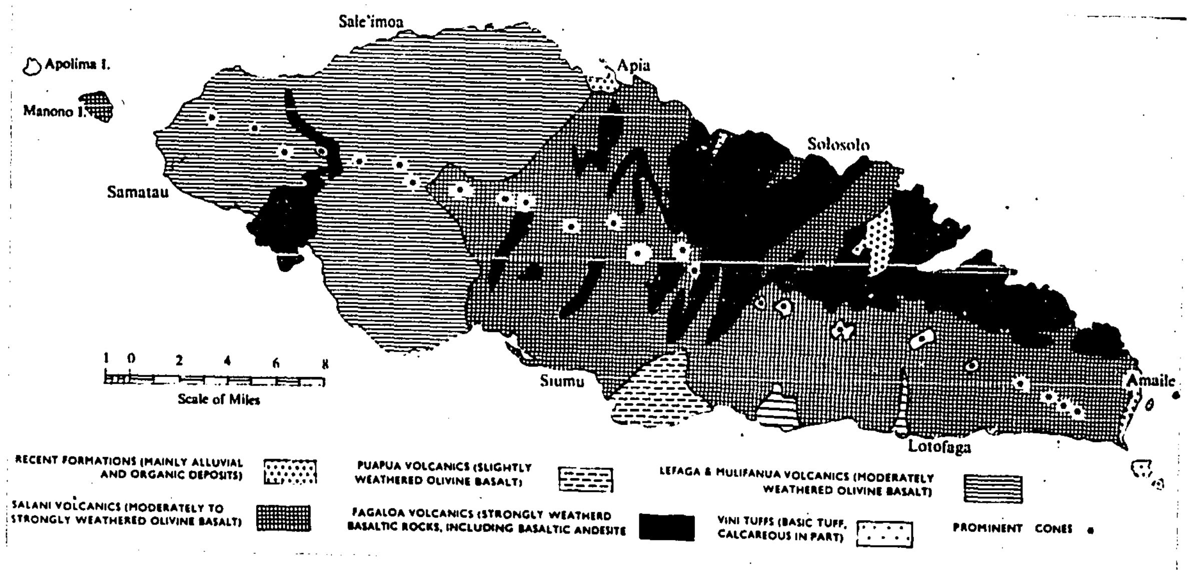
Geology

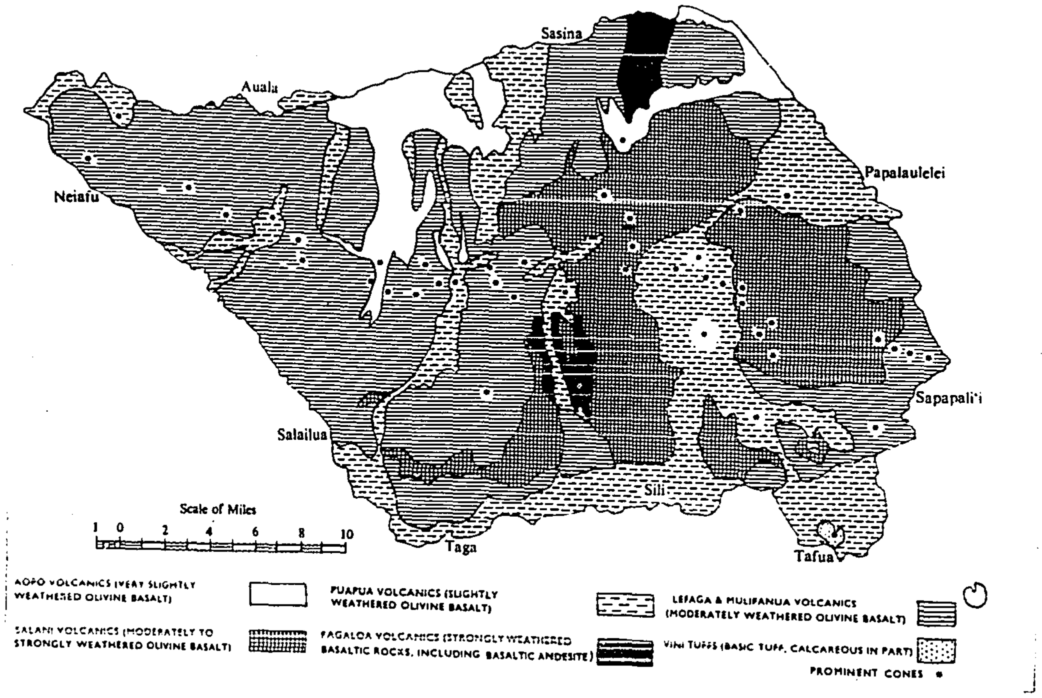
Time is and has been an important factor in soil formation in many Pacific high islands. Cycles of volcanism and erosion, rather than one period of volcanic activity, have formed the islands. Kerr and Wood (1959) have recognized five distinct periods of volcanic activity in Western Samoa. They have correlated soil properties, such as depth of solum and boulderness, with these periods.

Volcanic activities produced two broad elongated shield-shaped basaltic cones that appeared above the ocean floor during the late Tertiary period (Sterns, 1944). Lavas of this volcanism, Fagaloa volcanics (Figs. 1 and 2), consist of interstratified aa and pahoehoe rocks, rubbly scoria, brown ash, and basaltic dikes. Rock types (Kerr, 1959;

FIGURE 1. GENERALIZED GEOLOGIC MAP OF UPOLU
(Wright, 1963)

FIGURE 2. GENERALIZED GEOLOGIC MAP OF SAVAI'I
(Wright, 1963)


Sale'imoa
Apolima I.
Manono I.
Apia
Solosolo
Samatau
Siumu
Amaile
Lotofaga
1 0 2 4 6 8
Scale of Miles
RECENT FORMATIONS (MAINLY ALLUVIAL AND ORGANIC DEPOSITS)
PUAPUA VOLCANICS (SLIGHTLY WEATHERED OLIVINE BASALT)
LEFAGA & MULIFANUA VOLCANICS (MODERATELY WEATHERED OLIVINE BASALT)
SALANI VOLCANICS (MODERATELY TO STRONGLY WEATHERED OLIVINE BASALT)
FAGALOA VOLCANICS (STRONGLY WEATHERD BASALTIC ROCKS, INCLUDING BASALTIC ANDESITE
VINI TUFFS (BASIC TUFF, CALCAREOUS IN PART)
PROMINENT CONES


Sasina
Auala
Papalaulelei
Neiafu
Sapapali'i
Salailua
Sili
Taga
Tafua
Scale of Miles
1 0 2 4 6 8 10
AOPO VOLCANICS (VERY SLIGHTLY WEATHERED OLIVINE BASALT)
PUAPUA VOLCANICS (SLIGHTLY WEATHERED OLIVINE BASALT)
LEFAGA & MULIFANUA VOLCANICS (MODERATELY WEATHERED OLIVINE BASALT)
SALANI VOLCANICS (MODERATELY TO STRONGLY WEATHERED OLIVINE BASALT)
FAGALOA VOLCANICS (STRONGLY WEATHERED BASALTIC ROCKS, INCLUDING BASALTIC ANDESITE)
VINI TUFFS (BASIC TUFF, CALCAREOUS IN PART)
PROMINENT CONES

Macdonald, 1944; Bartrum, 1927) range from picrite to olivine basalt, although feldspathic basalt, horneblendite, andesite, and trachyte are present.

Weathering of the Fagaloa volcanics has produced deep soil, usually varying from three to five feet. Gently sloping flows of the younger volcanics surround the steep weathered slopes and sharp ridges of the Fagaloa volcanics. Streams of any appreciable size occur only in the Fagaloa volcanics.

After the erosional period (early to middle Pleistocene) vast quantities of lava built Upolu to 3,000 feet and Savai'i to 4,000 feet. Lavas of this period of volcanism designated Salani volcanics, are fine grained grey-black porphyritic basalts that grade to vesicular basalt and rubbly aa. They belong to a restricted suite of picrite basalt, olivine dolerite and basalt.

The Salani volcanics are much less weathered less eroded than the Fagaloa volcanics. Soil varying in depth from 12 to 24 inches covers the Salani weathered rocks that overlie the old reddish soil horizon formed on the Fagaloa rocks.

During the closing stages of the late Pleistocene, there was another period of quiescence. During this period, corresponding to the end of the last interglacial period, a 200-foot lowering in sea level caused increased erosion that formed amphitheatre-headed canyons. This erosional period ceased with renewed volcanic activity.

Throughout the last glacial period extensive Mulifunua lavas erupted. These lavas covered large areas of Upolu and raised considerable portions of Savai'i above sea level.

The Mulifunua lavas are grey-black, vitreous, porphyritic and nonporphyritic basalts interbedded with aa. There is a strong petrologic similarity between rock of Mulifunua and Salani volcanics indicating a possible overlapping of volcanic activity.

The lavas from these volcanics are weathered to a moderate degree and are relatively uneroded. Large boulders on the surface are common. Depth of the soil is usually 12 inches or less.

With rapid rise in sea level during the post glacial period, the ocean covered many of the large fans of Mulifunua lavas. A few aa lavas, called Lefaga volcanics, erupted during the early Holocene period. These lavas, representing picrite basalts and dolerite, are dark-grey and black feldspathic porphyritic basalts with greenish and red scoria in irregular beds.

Puapua volcanics erupted from the Post-Flandrian Thermal Maximum until historical times, covering extensive areas of Savai'i and a small area of Upolu. The volcanic activity in historical times, Aopo volcanics, has occurred only on Savai'i. The earliest recorded eruption was in 1760 near the village of Aopo. Additional volcanic activity has occurred during a period from 1902 to 1911 (Jensen, 1907). Future volcanic activity is possible.

Climate

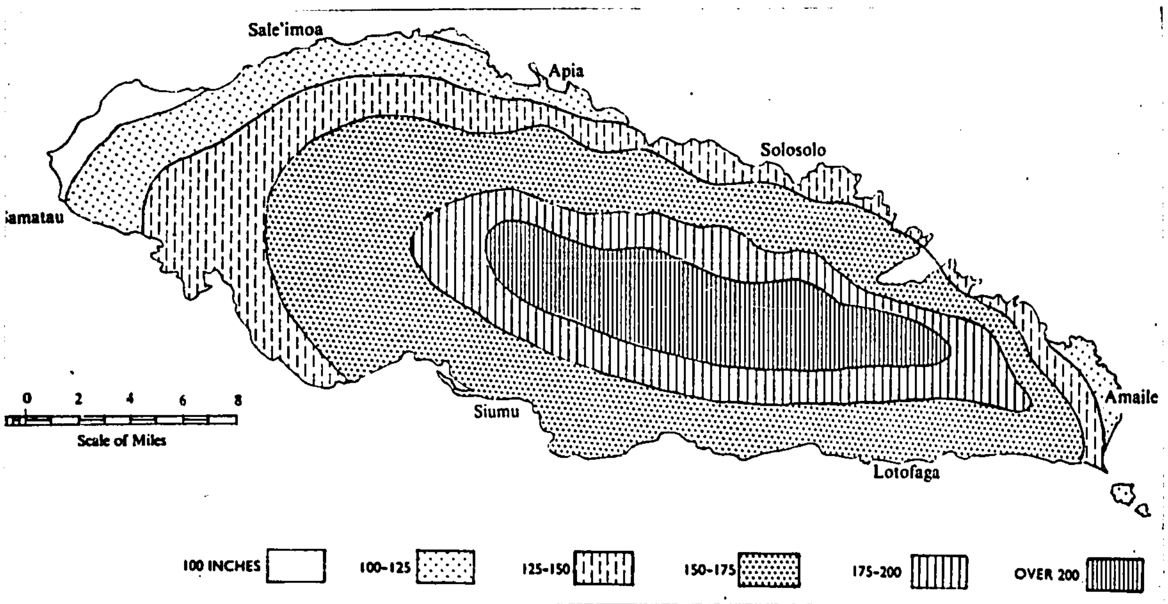
Direction of the prevailing winds and island elevation govern the climatic pattern of Western Samoa. The prevailing winds flow parallel to the central ridges (from SE to NW producing a concentric climatic pattern around each island (Figs. 3 and 4). If the prevailing winds were oriented only a few degrees north or south from their present direction, they should produce an orographic pattern like that of Oahu where dry areas occur on Leeward sides of the mountains. The rainshadow effect occurs to a minor degree on the western coast of Savai'i.

As the island elevation increases, rainfall is believed to vary from 80 to 90 inches mean annual rainfall (MAR) at the coast to more than 250" MAR in the highlands of Savai'i. Temperature decreases with increasing elevation at a rate of 0.65°C/100m (Curry, 1955). Because the islands remain below an inversion layer, there are no erratic changes in rainfall pattern with increasing elevation.

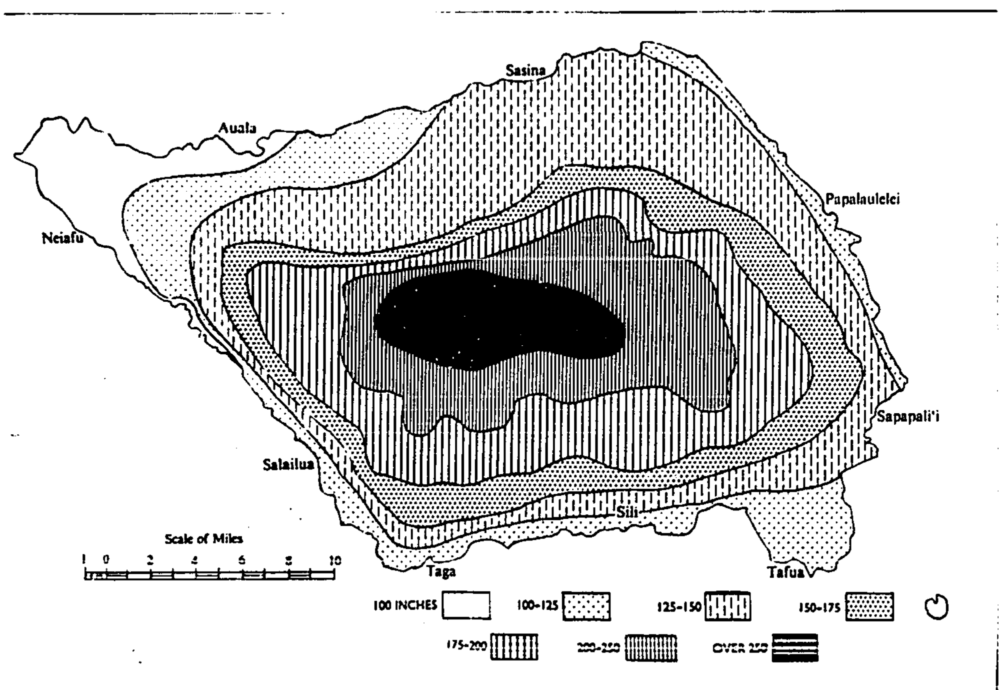
The climatic information for Western Samoa is unfortunately limited and unreliable. The only recorded data are those collected by the plantations along the coast. Generalizations about climate data on the inland portions of the islands are extrapolations of these data (Curry, 1955;

FIGURE 3. MEAN ANNUAL RAINFALL MAP OF UPOLU
(Wright, 1963)

FIGURE 4. MEAN ANNUAL RAINFALL MAP OF SAVAI'I
(Wright, 1963)



Sale'imoa
Apia
Solosolo
amatau
Amaile
Siumu
Lotofaga
0 2 4 6 8
Scale of Miles
100 INCHES
100-125
125-150
150-175
175-200
OVER 200



Sasina
Auala
Papalaulelei
Neiafu
Sapapali'i
Salailua
Sili
Scale of Miles
Taga
Tafua
100 INCHES
100-125
125-150
150-175
175-200
200-250
OVER 250

Wright, 1963). The following discussions, therefore, concern relative changes in rainfall and temperature that define the climatic zones (Figs. 5 and 6).

In the lowlands (0-750') the western coastal areas are very hot (78° MAT) and moderately wet (90-100" MAR). Each year these areas have several dry months receiving rainfall of less than three inches per month although the MAR is 80 to 90 inches. The evapotranspiration for these months frequently exceeds rainfall (Curry, 1955). The remaining portion of the lowlands is warm (78° MAT) and wet (100-125" MAR with one dry month) along the northern coastal areas and very warm and very wet (125-150" MAR with one to three moderately dry months) along the southern and eastern coastal areas. These areas suffer from periodic droughts.

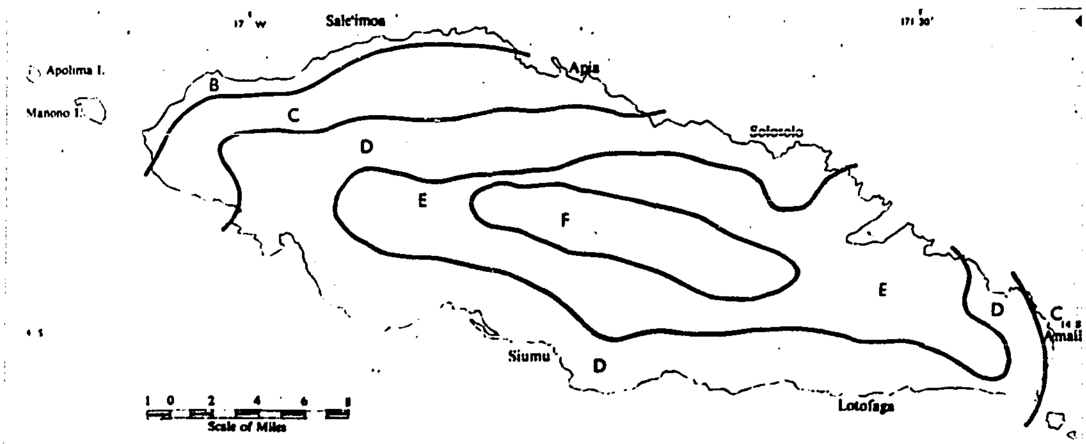
The foothills (750-2,000') of both islands are warm (78°F MAT) and very wet (150-175 MAR). Water percolates through the soil most of the year. The only foothills having a dry season are those on the western end of Savai'i where the rainshadow produces one to two moderately dry months (100-150 MAR).

The upland areas (2,000-4,000') have a cool (69°F) and very wet (175-200' MAR) climate with no dry period. Soils are excessively leached throughout most of the year.

The highland regions (4,000-6,000") have a cool (64°F) and extremely wet (200-250+" MAR) climate. This area is

FIGURE 5. CLIMATIC ZONES OF UPOLU (Wright,1963)

FIGURE 6. CLIMATIC ZONES OF SAVAI'I (Wright, 1963)



LOWLAND
(mean annual temperature 78 F)

B. MODERATE DRY SEASON.
2 months very dry
3-4 months moderately dry
Mean annual rainfall 90-100 inches.

LOWLAND AND FOOTHILL.
(mean annual temperature 78-71 F)

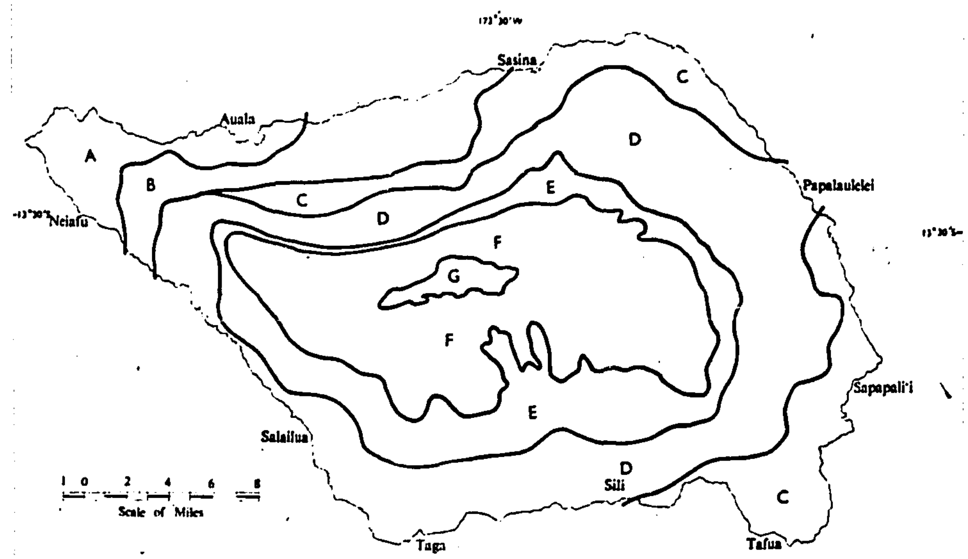
C. WEAK DRY SEASON.
1 month very dry
3 months moderately dry.
Mean annual rainfall 100-130 inches

D. VERY WEAK DRY SEASON.
No very dry months
1-2 months moderately dry.
Mean annual rainfall 130-175 inches.

E. NO DRY SEASON.
Mean annual rainfall 130-175 inches.

UPLAND
(mean annual temperature 71-67 F)

F. NO DRY SEASON.
Mean annual rainfall 175-200 inches



LOWLAND
(mean annual temperature 78° F)

A. MODERATE TO STRONG DRY SEASON.
3 months very dry
4-6 months moderately dry.
Mean annual rainfall. 85-90 inches

B. MODERATE DRY SEASON.
2 months very dry
3-4 months moderately dry
Mean annual rainfall. 90-100 inches.

LOWLAND AND FOOTHILL.
(mean annual temperature 78°-71° F)

C. WEAK DRY SEASON.
1 month very dry
3 months moderately dry.
Mean annual rainfall 100-130 inches

D. VERY WEAK DRY SEASON.
No very dry months
1-2 months moderately dry.
Mean annual rainfall 130-175 inches.

E. NO DRY SEASON.
Mean annual rainfall 130-175 inches.
172°30'W

UPLAND
(mean annual temperature 71°-67° F)

F. NO DRY SEASON.
Mean annual rainfall 175-200 inches.

HIGHLAND
(mean annual temperature 66°-60° F)

G. NO DRY SEASON.
Mean annual rainfall ca. 200 inches

mostly swamps. Soils are extremely acid, peaty, and waterlogged.

Vegetation

As in most Pacific high islands, there is a correlation between vegetation and climatic conditions. Recent vegetation cover has replaced much of the original plant cover destroyed or modified by man and recent volcanic activity in Western Samoa (Wright, 1963). Both Thompson (1953) and Wright give complete listings of vegetation types.

Lowland forests have virtually no epiphytes and little undergrowth. Ground cover consists of few ferns and creepers with thin or no litter. Trees are about 75 feet high, two feet in diameter and stand 45 feet apart. Thin saplings are 20 to 45 feet in height and closely spaced.

There is no sharp distinction between lowland forests and foothill forests. Some prominant species in the lowlands are also present in the foothills. Other lowland species usually disappear above 750'. With slightly increased rainfall the south coast has a good fern cover including many perched ferns and creepers at 700'. At 1,000 feet thick moss hangs on most trees. On both the north and south sides of the islands, at 1,500 feet elevation, trees are 80 feet high and 60 feet apart. There are numerous small and intermediate trees. Litter is approximately one-half inch deep.

At 2,000 feet elevation the trees average 70 feet in height and are 45 feet apart. Dense ferns and vines are common. Tree ferns may reach the height of the mossy trees (see Fig. 16).

Above 2,000 feet the proportion of ground and tree ferns of the upland forests increases significantly. Lichen, mosses, and epiphytes cover the trees (see Fig. 17). The largest trees in the canopy are identical to those of the foothills. Leaf litter varies from one to three inches in depth.

The highland forests, above 4,000 feet occur only on Savai'i. The trees are almost entirely covered with lichen and epiphytes and few are higher than 50 feet. Tree ferns, ground ferns, and ground mosses are abundant. On exposed ridges much of the forest is low, dense shrub. Forest litter is thick and peaty.

Wright (1963) commented that "the overall impression of the pattern of vegetation in Western Samoa is one of weakly zoned forest communtions." Some of the vegetation occurs in all zones with maximum development in one particular zone while other species occur at either low or high altitudes. Wright found no evidence for any species to have a stronger influence on soil formation than any other species.

MATERIAL AND METHODS

Sample Collection

Wright's system of classification (1963) provided a guide for the selection of the soil series. The New Zealand soils Bureau provided some of the samples. Dr. L. D. Swindale and this writer collected the remainder during field trips to Western Samoa in August, 1967 and July, 1968. The soil series which were selected covered most climatic zones and provided sequences with three different ages. Locations of the sampling sites are given in Figs. 7 and 8.

The first sequence included the soil series Vaisala, Sataua, Saleimoa, Lefaga, Tanumalala, Atu, Mauga, and Salega. The soils of the second sequence were Moamoa, Falealili, Fagaga, Solosolo, Etimuli, Afiamalu, Fiamoe, and Tiavi. The soils of the third sequence were Vaipouli, Sauaga, Luatuanu'u, Upolu, and Alafua.

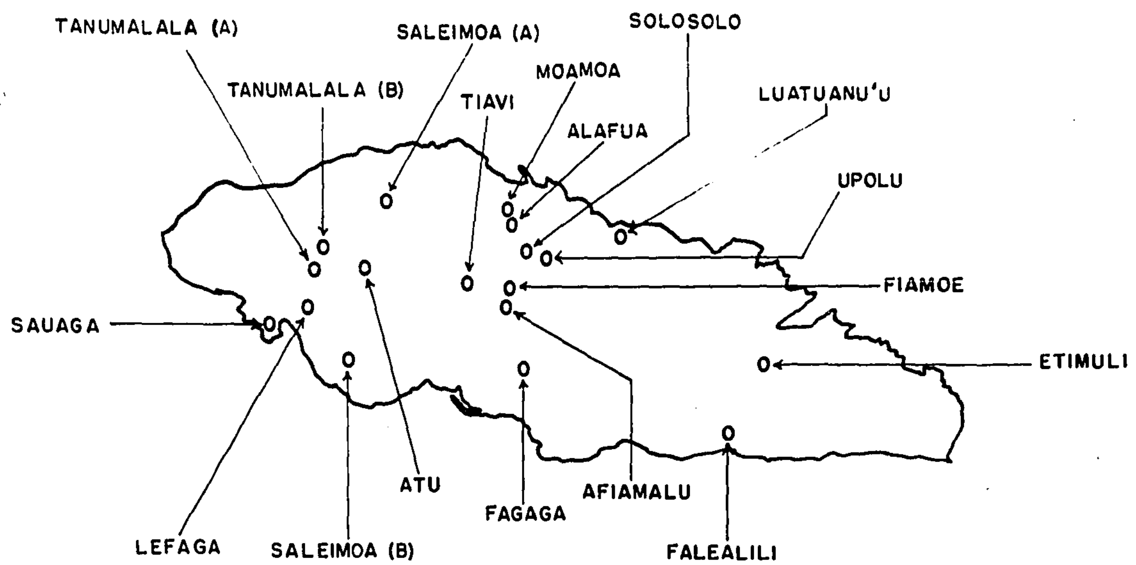
The profiles, selected to be representative of their mapping units, were sampled to a depth of three to four feet or to rock. Morphological characteristics of the profiles were described prior to sampling. Each horizon sample weighed approximately five pounds,

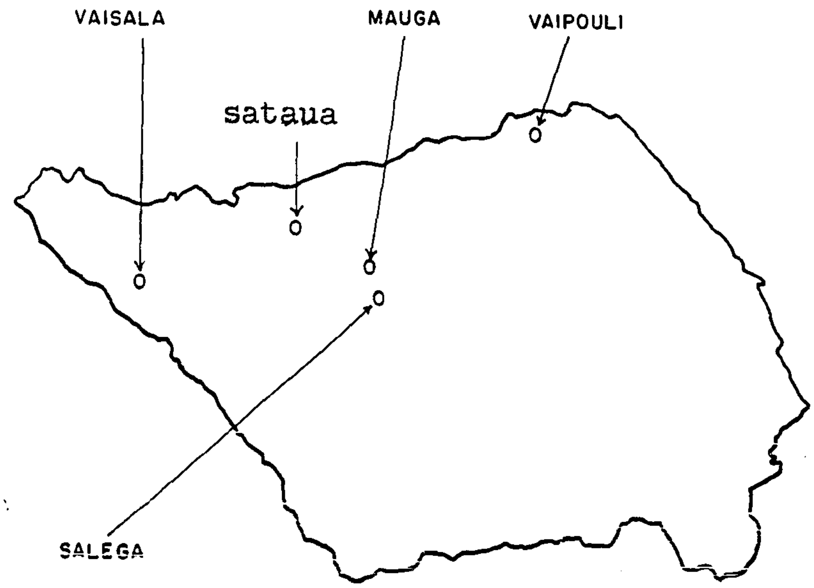
Laboratory Preparation

A one pound representative subsample of each sample was air dried for a period of two to three days. Of each

FIGURE 7. LOCATION OF SAMPLING SITES ON UPOLU

FIGURE 8. LOCATION OF SAMPLING SITES ON SAVAI'I


TANUMALALA (A)
SALEIMOA (A)
SOLOSOLO
MOAMOA
TANUMALALA (B)
TIAVI
LUATUANU'U
ALAFUA
UPOLU
FIAMOE
SAUAGA
ETIMULI
ATU
AFIAMALU
FAGAGA
LEFAGA
SALEIMOA (B)
FALEALILI


VAISALA
MAUGA
VAIPOULI
sataua
SALEGA

dried sample, three-quarters was ground to 10 mesh and the remaining quarter was ground to 100 mesh.

Chemical Analyses

Soil pH

Soil PH was determined in a suspension of 1:5 soil-water ratio and a suspension of 1:5 soil - N KCl ratio. A Beckman Expandomatic PH meter was used for the measurements. The suspensions were allowed to equilibriate for one hour. Measurements were taken 45 seconds after stirring.

Organic Carbon

Organic carbon, determined on air dried 100-mesh soil, was oxidized with chromic acid in the presence of a catalyst, concentrated sulfuric acid. The chromic acid remaining after digestion was back titrated with ferrous sulfate. A recovery factor of 77 was used (Jackson, 1958).

Total Nitrogen

Kjeldahl's method was used to determine total nitrogen on soil samples ground to 100 mesh. The organic matter was oxidized by concentrated H_2SO_4 in the presence of potassium, ferrous, and cupric sulfates. The nitrogen was converted to ammonium sulfate. The ammonia from ammonium sulfate was distilled into boric acid to form ammonium borate. The ammonium borate was titrated with standard H_2SO_4 with use of a mixture of methyl red-methylene blue as an indicator, Cation Exchange Capacity

The cation exchange capacity was determined on air dried 10 mesh soil. The exchange sites of the soil were saturated with NH_4^+ by leaching the soil with N NH_4 OAc buffered at pH 7. The leachate was saved for analysis of exchangeable bases. The soil sample was washed five times with 50 ml aliquots of methly alcohol.

Immediately after the soil was washed it was placed into an Erlenmeyer flask containing four percent KCl and was allowed to equilibriate for one hour. KCl was used to exchange the NH_4^+. This suspension was filtered and the filtrate was distilled with 1:1 NaOH into a four percent boric acid solution. The absorbed ammonium in the boric acid was titrated with standard H_2SO_4 using a mixture of methyl red methylene blue as an indicator.

The NH_4OAc leachate was analyzed for the exchangeable bases calcium, magnesium, sodium, and potassium. The calcium and magnesium were determined by means of a Perkin Elmer atomic adsorption unit and sodium and potassium were determined by means of a Beckman DU flame spectrophotometer.

Free Iron Oxides

The free iron oxides were determined on 100-mesh oven dried soils by the method described by Kilmer (1960). Reduction of sample size to 0.5 grams was necessary to extract all the free iron oxides before exhaustion of dithionite.

Mineralogical Analyses

Clay Preparation

Twenty-five grams of soil were weighed and placed in 600 ml beakers. Thirty percent H_2O_2 was added to the soil at 5 ml increments to oxidize the organic matter. If the soil contained very high amounts of organic matter, the suspension was heated on a steam bath and the peroxide treatment was continued for several days. After the organic matter had been oxidized, the soil was transferred to a centrifuge tube. The soil was acidified with PH 5 NaOAc buffer (Jackson, 1965), and Fe extracted with dithionite in the presence of sodium citrate. Because the soils were known to contain high amounts of free iron oxides, the extraction process was repeated twice. Then the samples were boiled for five minutes in two percent Na_2CO_3 and dispersed with distilled water.

The clays were separated by centrifuging at 750 rpm for three minutes. The supernatant liquid containing the clays was poured into a large beaker. This process was repeated five to six times to remove most of the clays. The clay suspension was slowly evaporated on a hot plate to concentrate the clays. The concentrated clay suspension was stored in polyethylene bottles. Five-ml aliquots of the concentrated clay suspensions were placed in weighing bottles and evaporated to obtain the exact clay concentration.

Preparation of Clay Slides

Enough clay suspension was pipetted into two centrifuge tubes to produce 30 mg of clay in each tube. Thirty ml of $\underline{N}$ KOAc were placed in one tube and 30 ml of $\underline{N}$ Mg OAc were placed in the second tube. Both centrifuge tubes were heated to 90°C for one hour. The tubes were centrifuged at 2,000 rpm and the supernatant liquid discarded. A small amount of distilled water was added to each tube to mix the clay sediment. The suspension was pipetted evenly onto clean glass slides and allowed to air dry.

Several samples were known to be high in amorphous material. The clay slides of these materials had a tendency to curl and break upon drying. This situation was remedied by the placing of a small amount of clay suspension on the center of the slide in such a way that the suspension did not touch the edge of the slide. These slides were placed in an air conditioned room to retard rapid drying.

The preferentially oriented potassium-saturated clays were examined by X-ray diffraction analysis after being dried at room temperature and after being heated to 350°C for two hours and to 550°C for two hours. In the event the clay sample curled off from the glass slide after being heated at 350°C, a smaller sample was used. The preferentially oriented magnesium-saturated clays were X-rayed before and after glycolation.

The X-ray diffraction patterns were obtained on a Phillip-Norelco Diffractometer using Cu radiation at a scanning speed of $2^{o}2\theta$/minute. Powder samples of the sand plus silt fractions were also analyzed.

Differential Thermal Analysis

Differential thermal analysis was performed on 100-mesh whole soil by use of Stone's controlled Environment System. A one-gram sample of soil was placed in an atmosphere of 57 percent relative humidity for two days. A 0.1 g subsample was thoroughly mixed with 0.1 g of calcined alumina. Nitrogen was passed through the sample to supress the oxidation of organic matter. The sample was heated at a constant rate of 10^{o}/minute from room temperature to $1,050^{o}C$. Differential thermal analysis was used to detect gibbsite, kaolin, and relative amounts of amorphous materials.

GENESIS AND CLASSIFICATION OF WESTERN SAMOA SOILS

The soils represented in this study comprised three sequences differing in age but having the same sequence of climatic zones. This arrangement allowed comparison of soils formed on parent material of different ages but formed under similar climatic conditions. It also allowed comparisons of soils formed from the same age parent material but under different climatic environments. The profile descriptions, chemical, and mineralogical analyses are given in Appendix I. Summaries of the mineralogical analyses and environmental characteristics are in Tables I and II. The classifications of the soils are given in Table III.

Lefaga Sequence

The soil series comprising this sequence are Vaisala, Sataua, Saleimoa (A and B), Lefaga, Tanumalala (A and B), Atu, Mauga, and Salega. The parent rock is essentially aa lava that was erupted during the Holocene period. Atu and Salega are exceptions, the parent rock being pahoehoe and ash, and scoria, respectively. This sequence represented the youngest soils in this study.

Morphologically, the soils appeared to be relatively unweathered. The depth of solum rarely attained 60 cm in the lowlands and 90 cm in the foothills and uplands. The profiles generally had considerable amounts of cobbles and boulders. Chemically and mineralogically a wide range of

TABLE I. SUMMARY OF THE MINERALOGICAL ANALYSES

	Soil Series	Mixed Layer	Kaolin	Gibbsite	Amorphous
Lefaga	Vaisala	xx	x		
	Sataua	x			xx
	Saleimoa	xx	x		xx
	Lefaga	x		x	xx
	Tanumalala			xx	
	Atu				xxx
	Mauga			x	xxx
	Salega			x	xxx
Falealili	Moamoa			x	
	Falealili			xxx	
	Fagaga			xxx	
	Solosolo			xxxx	
	Etimuli			xxxx	
	Afiamalu		xxx	xxxx	
	Fiamoe			xx	
	Tiavi		xxx	x	
Papaloa	Vaipouli			xxxx	
	Sauaga		xxx	x	
	Luatuanu'u		xxx	x	
	Alafua		xxx	x	
	Upolu		xx	xx	

x-Trace
xxx-Moderate
xx-Small
xxxx-Large amounts

TABLE II. ENVIRONMENTAL CHARACTERISTICS

	Soil Series	Rainfall	Temp. °F.	No. Months Dry	Parent Material
	Vaisala	90"	78	3	Lava
	Sataua	100"	78	2	Lava
	Saleimoa	120"	78	1-2	Lava
Lefaga	Lefaga	130"	75	0-1	Lava
	Tanumalala	140"	72-74	None	Scoria Lava
	Atu	150"	72	None	Scoria Lava
	Mauga	160"	72	None	Lava
	Salega	175"	69	None	Lava
	Moamoa	120"	78	0-1	Lava
	Falealili	130"	78	None	Lava
	Fagaga	140"	74-78	None	Lava
Falealili	Solosolo	150"	72	None	Lava
	Etimuli	175"	72	None	Lava
	Afiamalu	200"	69	None	Scoria
	Fiamoe	200"	69	None	Scoria Lava
	Tiavi	200"	69	None	Lava
	Vaipouli	120"	78	0-1	Lava
	Sauaga	130"	78	None	Lava
Papaloa	Luatuanu'u	150"	72	None	Lava
	Upolu	160"	72	None	Lava
	Alafua	120"	78	0-1	Alluvium

TABLE III. CLASSIFICATION OF THE SOILS IN THE U. S. COMPREHENSIVE SOIL CLASSIFICATION SYSTEM

Lefaga Sequence

Order	Suborder	Great Group	Subgroup	Family	Soil Series
Inceptisol	Tropept	Eutropept	Lithic Eutropept	Clayey-Skeletal, Mixed, Isohyperthermic	Vaisala
Inceptisol	Tropept	Dystropept	Lithic Dystropept	Clayey-Skeletal, Mixed, Isohyperthermic	Sataua
Inceptisol	Tropept	Dystropept	Typic Dystropept	Clayey-Skeletal, Mixed, Isohyperthermic	Saleimoa
Inceptisol	Tropept	Dystropept	Typic Dystropept	Clayey-Skeletal, Mixed, Isohyperthermic	Lefaga
Inceptisol	Tropept	Dystropept	Oxic Dystropept	Very fine, Oxidic, Isothermic	Tanumalala
Inceptisol	Aquept	Andaquept	Histic Andaquept	Fine, Mixed Isothermic	Atu
Inceptisol	Tropept	Humitropept	Histic Humitropept	Clayey-Skeletal, Mixed, Isothermic	Mauga
Inceptisol	Andept	Hydrandept	Typic Hydrandept	Thixotropic Isothermic	Salega

TABLE III. (Continued) CLASSIFICATION OF THE SOILS IN THE U. S. COMPREHENSIVE SOIL CLASSIFICATION SYSTEM

Falealili Sequence

Order	Suborder	Great Group	Subgroup	Family	Soil Series
Inceptisol	Tropept	Dystropept	Oxic Dystropept	Clayey-Skeletal, Oxidic, Isohyperthermic	Moamoa
Inceptisol	Tropept	Dystropept	Oxic Dystropept	Clayey-Skeletal, Oxidic, Isohyperthermic	Falealili
Inceptisol	Tropept	Dystropept	Oxic Dystropept	Clayey-Skeletal, Oxidic, Isohyperthermic	Fagaga
Inceptisol	Tropept	Humitropept	Oxic Humitropept	Fine, Oxidic, Isothermic	Solosolo
Inceptisol	Tropept	Humitropept	Oxic Humitropept	Fine, Oxidic, Isothermic	Etimuli
Inceptisol	Tropept	Humitropept	Oxic Humitropept	Fine, Oxidic, Isothermic	Afiamalu
Inceptisol	Tropept	Humitropept	Oxic Humitropept	Fine, Oxidic, Isothermic	Fiamoe
Inceptisol	Tropept	Humitropept	Oxic Humitropept	Fine, Mixed Isothermic	Tiavi

TABLE III. (Continued) CLASSIFICATION OF THE SOILS IN THE U. S. COMPREHENSIVE SOIL CLASSIFICATION SYSTEM

Papaloa Sequence

Order	Suborder	Great Group	Subgroup	Family	Soil Series
Oxisol	Orthox	Haplorthox	Typic Haplorthox	Fine, Gibbsitic, Isohyperthermic	Vaipouli
Inceptisol	Tropept	Dystropept	Oxic-Ultic Dystropept	Very fine, Halloysitic, Isohyperthermic	Sauaga
Inceptisol	Tropept	Dystropept	Oxic Humitropept	Very fine, Halloysitic, Isohyperthermic	Luatuanu'u
Ultisol	Humult	Tropohumult	Humoxic Tropohumult	Very fine, Mixed, Isothermic	Upolu
Inceptisol	Tropept	Dystropept	Fluventic Oxic Dystropept	Very fine, Halloysitic Isohyperthermic	Alafua

soil properties existed.

Soils of the lowlands (Vaisala, Sataua, Saleimoa, and Lefaga) were only slightly weathered. Although these soils exist in a climatic environment of 90" MAR, there are one to three dry months per year. These dry months have a pronounced effect upon the mineralogy of these soils. Reference to Table I indicates that these were the only soils with weakly formed mixed layer material. The quantity of these minerals was small, but they were indicative of the weathering environment. Mixed layer minerals formed because (1) the parent material was young and through desilication released relatively large quantities of calcium and magnesium (indicated by the high amounts of exchangeable calcium and magnesium), and (2) leaching was not continuous and thus bases accumulated. When bases, particularly calcium and magnesium are abundant, a situation conducive to the formation of 2:1 or mixed layer minerals develops (Sherman and Uehara, 1956; Uehara and Sherman, 1956).

Vaisala soils were relatively unweathered. The depth of solum was rarely over 30 cm. The profile was bouldery with a mixture of organic matter and clay size material filling the interstices. The pH was slightly acid (6.0) and the base saturation was high at 77 percent. This soil was classified as lithic Eutropept.

Sataua soils showed less mixed layer development than Vaisala soils. The solum was also shallow and bouldery.

The organic carbon content was high at 17 percent and the base saturation decreased to 36 percent. This soil was classified as a Lithic Dystropept.

Both samples of the Saleimoa soil showed the best mixed layer mineral development. These soils exist under slightly higher rainfall (115" MAR) than the Vaisala or Sataua soils. The Saleimoa soils were generally deeper and less bouldery than the Vaisala or Sataua soils. The organic carbon content was still relatively high varying from 12 to 17 percent. Figure 9 shows the top of a typical Saleimoa profile. These soils were dark brown (10YR 3/3) to black (5YR 2/1), friable and had a weak to moderately strong structure Saleimoa soils were classified as Typic Dystropepts.

Lefaga soils were formed under a 130" MAR associated with a very weak dry season. This soil contained a trace of mixed layer mineral development. The soil pH was acid at 5.7 and the base saturation decreased to 25 percent at a depth of 45 cm. The organic carbon content was still high at 18 percent in the top soil.

The next soil series of the sequence, Tanumalala, receives a MAR of 150" and has a MAT of 72^{o}F. In this climatic environment, soil leaching and desilication occur rapidly. Gibbsite was the dominant mineral, iron oxides increased to 18 percent and the base saturation of the subsoil varied from three to 13 percent. The highly

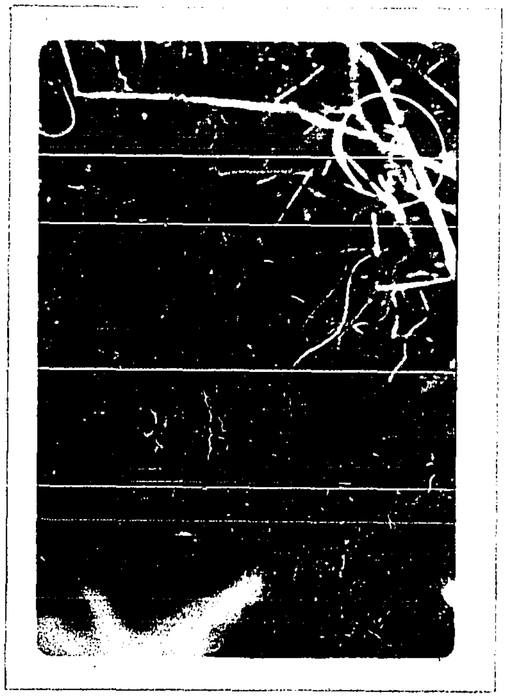


FIGURE 9. TOP HORIZON OF THE SALEIMOA (A) PROFILE

weathered nature of the soil may be due to the influence of an ash cover from Tafua Upolu cone and/or the nearly level topographic province that the soil occupies. The Tanumalala soils were classified as Oxic Dystropepts. Figure 10 shows a typical profile of the Tanumalala series.

Atu soils occurred along the Western end of the rift zone of Upolu. This soil, formed from pahoehoe, differed considerably from the other soils of this sequence. because Atu soils occurred on and near the rift zone, ash influenced their formation. The combined parent material was ash over pahoehoe. This ash mantle varied from 12 to 18 inches. Another interesting factor in the genesis of

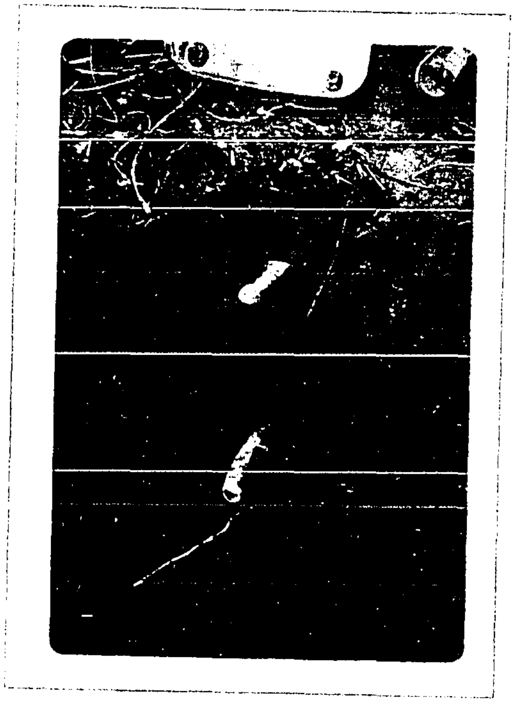


FIGURE 10. TANUMALALA (B)
SOIL PROFILE

these soils was drainage. Figures 11 and 12 show two Atu soil profiles taken within a few meters of one another. The only change in the environmental factors was that the soil in Fig. 11 was sampled where the pahoehoe had been fractured and there had been good drainage. The soils in Fig. 12 was underlain by solid pahoehoe (note bottom of Figure) where drainage of the soil was poor and the soil contained mottles. The dark top horizon was very high in organic carbon (22%) and the yellowish brown amorphous subsurface was formed from ash. Atu soils were commonly high in organic carbon, nitrogen, and exchangeable bases. Organic matter was high because impeded drainage, high

FIGURE 11. WELL DRAINED ATU SOIL

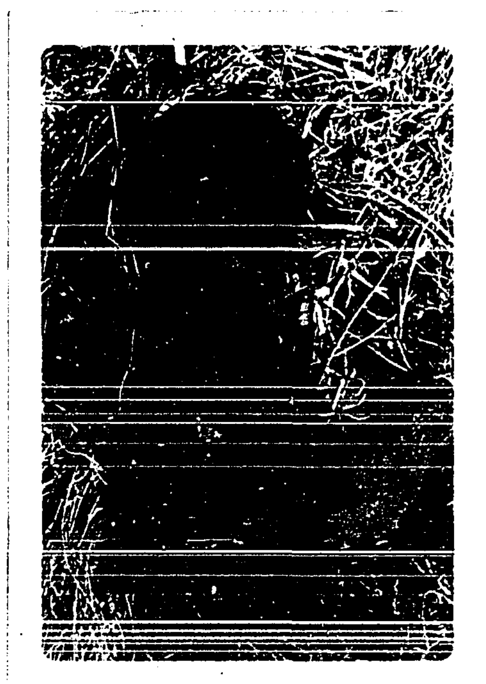


FIGURE 12. POORLY DRAINED ATU SOIL

rainfall, and low temperatures were not conducive to high mineralization rates. Figure 13 shows the general landscape of Atu soils. Atu soils were classified as Histic Andaquepts.

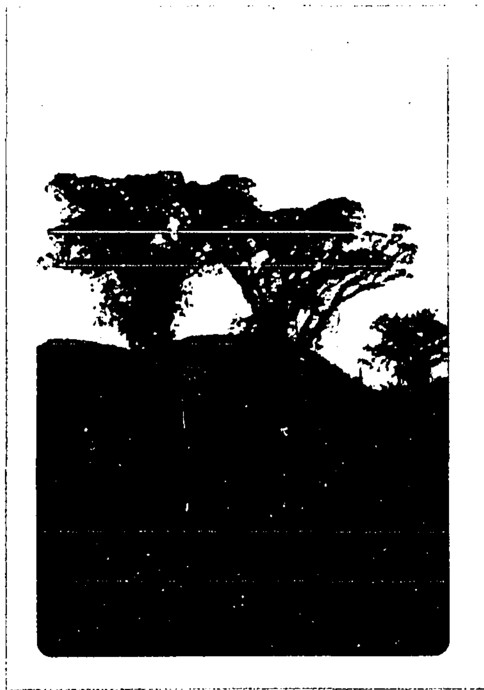


FIGURE 13. ATU SAMPLING SITE (TAFUA UPOLU CONE IN BACKGROUND)

The last two soils of this sequence are on Savai'i. Mauga, which Wright had previously called Lefaga, has been separated in this study from Lefaga on the basis of base saturation and distribution of organic carbon. It was more bouldery than Lefaga. The organic matter was distributed over 60 cm in depth (14% organic carbon). A typical profile consisted of many boulders with a peaty material filling the pores. The mineralogy of the soil consisted essentially of amorphous mineraloids with a trace of gibbsite. The cation exchange capacity was high (86 meq/100g) and base saturation was somewhat low (20%). This soil was classified as a Histic Humitropept.

The last soil belongs to the Salega series. This soil differed from Mauga in that the parent material was scoria and ash instead of aa lava. Salega soils contained high amounts of organic carbon 18% and were peaty in the top soil. The color was dusky red (2.5YR 2/2), a common feature of many of the soils formed from scoria. The mineralogy was predominantly amorphous material with a trace of gibbsite in the subsurface. The amorphous nature of the soil minerals was also indicated by the smeariness (Thixotropic), high CEC (80 meq/100g), and low base saturation (4%) (Sherman, et al., 1964). This soil dehydrates and hardens irreversibly when dried. Salega soils were classified as Typic Hydrandepts.

Falealili Sequence

The soils comprising this sequence were Moamoa, Falealili, Fagaga, Solosolo, Etimuli, Fiamoe, Afiamalu, and Tiavi. These soils were formed on the Salani volcanics extruded during the middle Pleistocene period. The series, originally separated on a climatic basis, can be divided into two subgroups: Oxic Dystropepts and Oxic Humitropepts. All the soils are highly weathered and are generally oxidic in nature.

Moamoa, Falealili, and Fagaga soils were formed in areas with a temperature of 78°F MAT and rainfall varying from 130 to 150 inches MAR. Although the solum has considerable quantities of unweathered rock (Figure 14) the predominant mineralogy was gibbsite and oxides of iron. The pH of these soils was acidic ranging from 5.4 to 5.7. Base saturation in the subsurface horizon ranged from five to 22 percent.

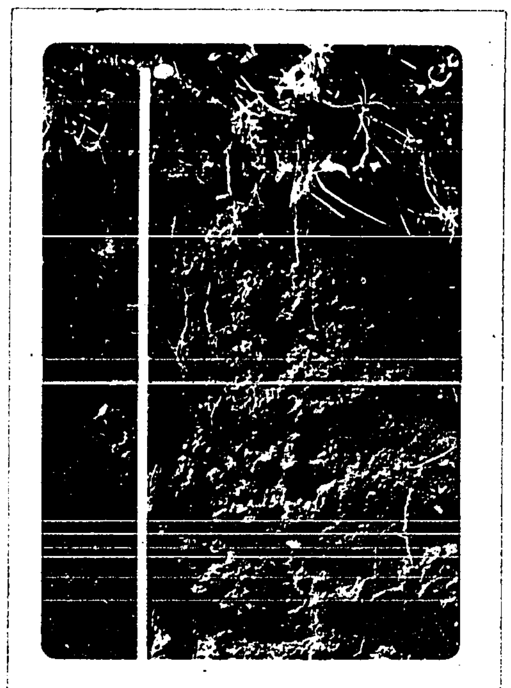


FIGURE 14. FAGAGA SOIL PROFILE
(NOTE ABUNDANCE OF ROCKS)

The next two soils of the sequence, Solosolo and Etimuli, were also gibbsitic and high in iron oxides. A characteristic of these soils was the positive ΔpH in the subsurface horizons. Generally, 20 to 22 percent free iron oxides in the presence of low organic carbon (1-2%) causes the soils to have a net positive charge. Sumner (1963) remarked that under field conditions the positive and negative changes largely neutralize each other. When the situation occurs the inorganic colloidal fraction loses its ability to retain nutrients. Under the combination of intense leaching and predominately positive changes in the subsurface colloidal fraction, management with respect to maintenance of good nutritional status, becomes very difficult.

A very high correlation (0.905) exists between total nitrogen and the soil cation exchange capacity. This relationship indicates that organic matter is the active fraction with respect to base retention and the role of the mineral fraction is small. Management practices in Western Samoa should be clearly oriented toward maintenance of a high level of organic matter in the soil. Figures 15 and 16 show an example of an Etimuli profile and the sampling site, respectively.

The last three soils, Afiamalu, Fiamoe, and Tiavi, are located near one another at the Taivi saddle in Upolu. Afiamalu is developed from ash and scoria, Fiamoe from

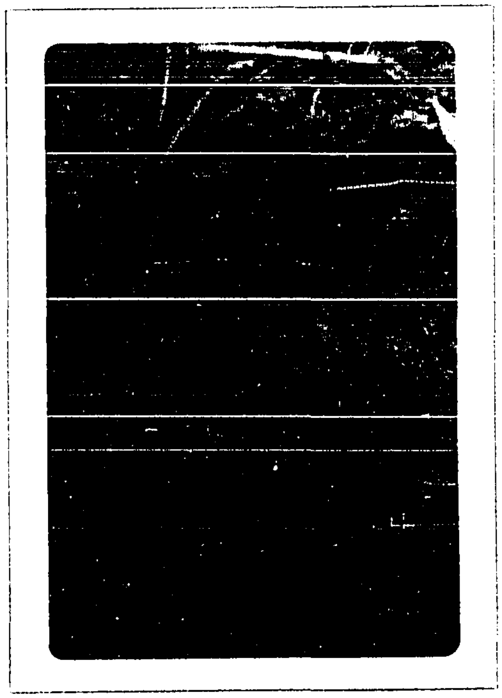


FIGURE 15. ETIMULI SOIL PROFILE

FIGURE 16. ETIMULI SAMPLING SITE

pahoehoe overlain by ash, and Tiavi on the side of a volcanic cone from pahoehoe. Afiamalu was unusual in that with increasing depth gibbsite decreased and halloysite increased. Although this soil appeared to be developed in ash, its highly weathered state does not permit identification of the parent rock. The base saturation was near zero, the cation exchange capacity was low (11 meq/100g) and the pH has been known to be as low as 3.8. In the bottom two horizons the high free iron oxide content of 30 percent was associated with a positive ΔpH. Another characteristic associated with Afiamalu soils was the high titanium oxide content (12%). Anatase appeared to be the dominant titanium mineral.

The shape of the water release curve of this soil was more like that of sand than clay due to the soil's high aggregate stability. Management of the Afiamalu soil under the 200 inch MAR is extremely difficult. Lime and fertilizer must be added every three to six months to maintain a proper nutritional status (Radford; 1968). Figure 17 shows the sampling area of the Afiamalu soil.

Fiamoe appears to be less weathered than Afiamalu soil. It lacked good kaolin mineral development and was somewhat lower in free iron oxides (22%). It is possible that the pahoehoe parent rock caused a decrease in weathering compared to the Afiamalu soil. The predominant mineralogy was gibbsite and amorphous material with a trace of halloysite.

FIGURE 17. AFIAMALU SAMPLING SITE

Tiavi, with pahoehoe parent material, showed good kaolin mineral development in all horizons. Two factors possibly influenced Tiavi soil formation. First, the soil was formed on pahoehoe which tends to weather more slowly than ash or scoria and second, the soil occurs on a relatively steep slope compared to the level area occupied by Fiamoe and Afiamalu. It is possible that soil is eroding and losing weathered materials thus exposing fresh material for weathering. Tiavi soil, nevertheless, is highly weathered as indicated by the high free iron oxide content (20%) and the low base status (8%). It is interesting to note that with this high free iron oxide content the Δ pH is negative, resulting from the presence of kaolin minerals.

Papaloa Sequence

The soils comprising the papaloa sequence were Vaipouli, Sauaga, Luatuanu'u, Upolu, and Alafua. These soils were found on the oldest volcanics erupted during the late Tertiary or early Pleistocene period. The predominant landform was steeply eroded volcanics with steep slopes.

The Vaipouli series was sampled on a level bench in Savai'i. The profile was highly weathered and extended to a depth of ten feet. The predominant mineral was gibbsite, and the free iron oxide content was 26 percent. The SiO_2 content was extremely low at 1.7%. Base saturation was near zero in the subsoil and the cation exchange capacity averaged about 11 meq/100g. Little saprolite was present and the subsoil structure (oxic horizon) was massive and dense. Figure 18 shows a representative profile of the Vaipouli series. This series was classified as a typic Haplorthox.

The sauaga and Luatuanu'u series occur on steep unstable slopes in Upolu. These soils were mainly halloysitic but did contain small quantities of gibbsite. Sauaga was the least weathered ofthe two with free iron oxides at 15 percent, the base saturation at 40 percent. The subsurface horizon of the Sauaga soils was compact and had clay skins.

The soil was classified as an Oxic-Ultic Dystropept being an intergrade toward Ultisol.

Luatuanu'u appeared to be more weathered than Sauaga due to the higher amounts of gibbsite, free iron oxides (20%), and lower base saturation (8%). Wright (1963) noted that large areas of Luatuanu'u soils were badly eroded. Saprolitic material often occurred within 30 cm of the surface. These soils were classified as Oxic-humitropepts.

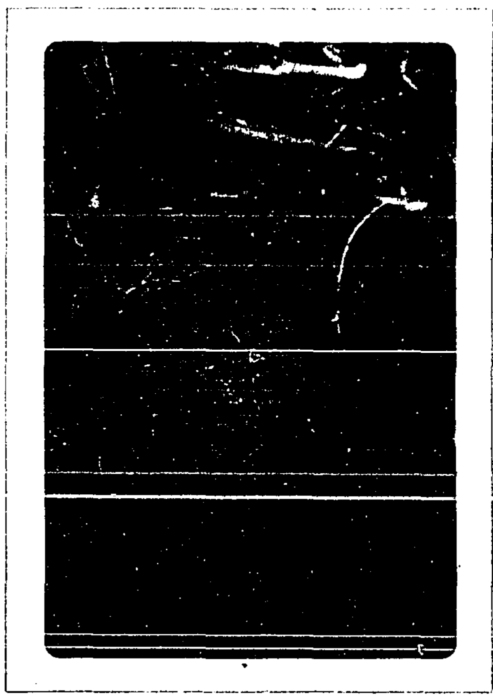


FIGURE 18. VAIPOULI SOIL PROFILE

Upolu soil is located on semi-stable areas of the Fagaloa volcanics. Erosion has occurred to a moderate degree but is not as severe as that of Sauaga and Luatuanu'u. The mineralogy of the Upolu soils was a mixture of gibbsite and halloysite. The free iron oxide content was high (20%) and the base saturation varied from 38 to 13 percent. The subsurface was firm and compact and had many continuous clay skins. This soil was tentatively classified as a Humoxic Tropohumult.

The Alafua series, an alluvial soil, occurs on Salani volcanics that juxtapose against a Fagaloa outcrop (Fig. 19). This soil was formed from the sediment of a stream that flows along the junction of the volcanics. The source of the sediments was primarily eroded material from the Fagaloa outcrop (Sauaga series), and some material from soils of the Moamoa series. The resulting mineralogy of the Alafua soils was predominantely halloysite with small amounts of gibbsite. This soil provides evidence that the Fagaloa volcanics are unstable and that the erosional process tends to remove material as quickly as it weathers.

The Alafua soils generally have moderate amounts of free iron oxides (15%), high base saturation (60 to 74%), and moderate amounts of organic carbon (4%). A gravel layer at a depth of 60 cm is rich in organic materials.

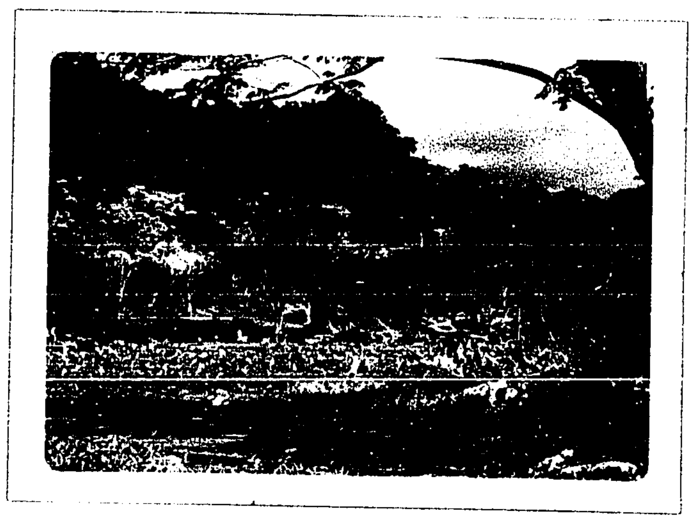


FIGURE 19. ALAFUA SAMPLING SITE (NOTE FAGALOA VOLCANICS IN BACKGROUND)

RESULTS AND DISCUSSION

Influence of Age

From the brief description of the sequences given above, several observations of the effect of age on soil formation in Western Samoa can be made. Table IV indicates that soils of the youngest sequence (Lefaga) were generally lower in free iron oxides but were higher in organic carbon, cation exchange capacity, and base saturation than the corresponding soils in the Falealili sequence. Exceptions were in the base saturation of the Mauga and Salega soils in which rainfall had a greater influence than the age of parent material. The mineralogical properties (Table I) are another indication of youth. The soils of the Lefaga sequence generally contained mixed layer minerals in the lower rainfall areas or amorphous material and gibbsite in the higher rainfall areas. Tanumalala showed maximum weathering indicated by high free iron oxide content and gibbsite mineralogy. Soils of the Falealili sequence were essentially gibbsitic with the exception of the Tiavi soil.

Another important aspect of age is the degree of disection. The Mulifanua and Salani volcanics were relatively undisected. The Fagaloa volcanics were highly disected and dominated by steep slopes. On these steep slopes, the rate of erosion was apparently sufficient to stabilize the weathering process at a point of halloysite formation.

TABLE IV. SOIL PROPERTIES OF THE SURFACE HORIZON

	Soil Series	% Fe_2O_3	% Organic Carbon	Meq/100g Cation Exchange Capacity	% Base Saturation
Fegaga	Vaisala	6.6	17.2	58.7	76.6
	Sataua	3.4	17.3	56.1	78.0
	Saleimoa	7.0	17.0	73.5	71.0
	Lefaga	7.2	17.9	64.0	57.0
	Tanumalala	18.1	7.6	35.6	44.0
	Atu	7.86	22.0	87.8	52.0
	Mauga	10.0	20.7	85.4	21.0
	Salega	5.7	18.4	78.0	4.0
Falealili	Moamoa	20.1	3.9	33.0	11.0
	Falealili	10.0	7.8	31.0	46.0
	Fagaga	14.0	10.0	43.0	28.0
	Solosolo	17.9	6.1	26.9	19.0
	Etimuli	20.7	5.1	24.6	8.0
	Afiamalu	25.0	8.4	26.0	7.0
	Fiamoe	22.1	11.9	46.7	11.4
	Tiavi	18.6	6.5	22.7	8.0
Papaloa	Vaipouli	19.3	5.8	21.4	39.0
	Sauaga	13.4	4.0	24.6	42.0
	Luatuanu'u	16.5	10.8	28.3	14.0
	Upolu	17.3	6.6	39.9	38.0
	Alafua	15.0	4.5	22.6	60.0

Influence of Rainfall

Base saturation and mineralogy of soils of the Lefaga sequence best illustrated the influence of rainfall. As rainfall increased from 90 inches to over 200 inches MAR, base saturation varied from 78 to four percent. The amount of free iron oxides tended to increase to a maximum of 18 percent in Tanumalala soils and to decrease with further increases in rainfall. With increasing rainfall, the general succession of mineral formation began with mixed-layer minerals, continued to gibbsite, and ended with amorphous material.

With increasing rainfall in the Falealili sequence, depth of solum and free iron oxides increased; but base saturation and the amount of boulders in the solum decreased. Overall, rainfall had a more pronounced effect on the soils of the Lefaga sequence than on the soils of the Falealili or Papaloa sequences, the reason being that age appeared to modify the rainfall effect.

R. W. Rex, et al. (1969) have found in Hawaiian soils a trend of increasing quartz in the surface soils with increasing rainfall. The origin of the quartz appears to be tropospheric dust deposited by rainfall of the northeast trade winds feeding off the westerly winds. A detailed examination of the X-ray diffraction patterns of both the clay and silt fractions of all the Western Samoa soils studied indicated that quartz is absent. This absence provides additional evidence to support the theory of tropospheric derivation of quartz in Hawaiian soils. Examination of meteorological maps of the Pacific Ocean indicates that the winds of the northern Pacific area travel clockwise while the winds of the southern Pacific travel counterclockwise. The clockwise wind movement of the north Pacific carries aerosolic dusts from the North American continent over the relatively short distance to Hawaii. The counterclockwise movement of winds in the south Pacific travel significantly greater distances from South America to Western Samoa.

The dominant weathering process in Western Samoa is parent rock desilication, through the rapid removal of bases by continuously percolating waters. The end products of weathering, hydrous oxides of aluminum and iron, tend to form and accumulate early in the weathering process. Electron micrographs of the Upolu subsoil showed two interesting features. First, the mean particle diameter was 0.1u to 0.5u and the halloysite material appeared to be tabular instead of tubular. The clay size material, generally lacked good morphological development. Second, a "gel-like" material with an average thickness of 100 A surrounded the clay particles (Fig. 20).

Recent work on Hawaiian soils (R. C. Jones, 1969) shows that a gel hull also surrounds the clay material of these soils. The exact nature and genesis of these gel hulls has

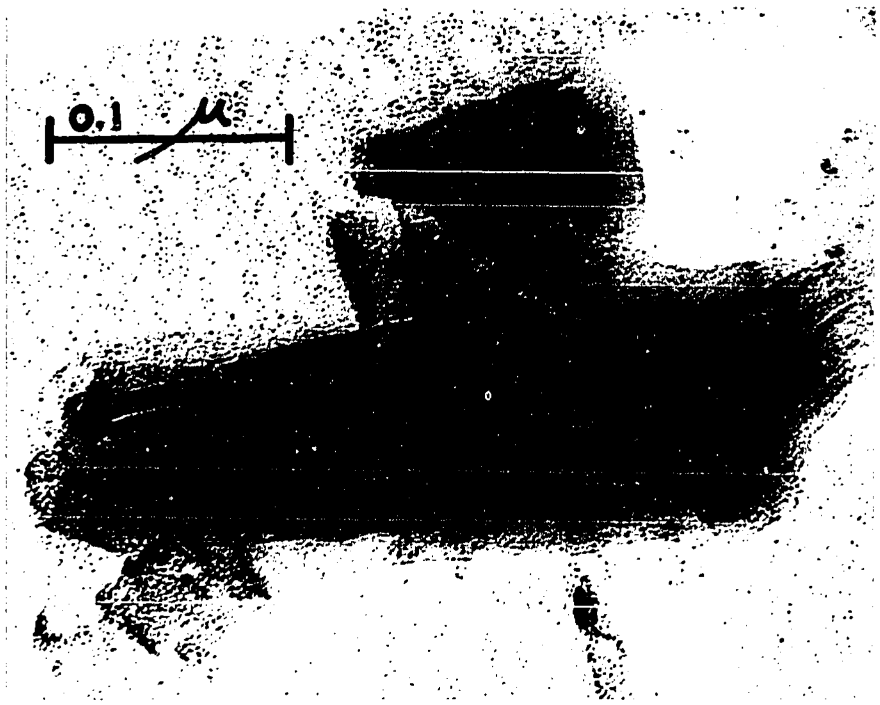


FIGURE 20. ELECTRON PHOTOMICROGRAPH OF THE UPOLU CLAY FRACTION ILLUSTRATING THE GEL HULL (315,000X)

not been determined. It is possible that the gel is amorphous and may be an intermediate weathering product of the original clay mineral.

A Note On Classification

In classification of the soils of Western Samoa, two points were kept in mind: (1) the soils were to be classified according to a widely used classification system, so that information on management and expected productivity could be transferred to Western Samoa from areas having similar soils and (2) the criteria used for classification were to be used as guidelines and not as rigid rules. It was considered most important that classification of a soil would enable predictions about soil behavior.

The soil series Mauga can be used to clarify point 2. Examination of the available data of this series in Appendix I indicates that the soils could be classified as a Hydrandept as defined in the U. S. Comprehensive Classification System (Soil Survey Staff, 1960, 1967). The base saturation was low, the cation exchange capacity was high, the minerals were essentially amorphous, and the soil tended to dry irreversibly upon dehydration. Although the parent material was lava instead of ash, it would be correct to classify the soil as a Hydrandept. The main factor that gave the soil the above characteristics was not amorphous hydrous aluminum silicates but the high content of organic matter

(39%). Although the organic matter content was sufficiently high for a Histosol classification, the organic matter was well decomposed and the soil profile was well drained, neither of which is characteristic of a Histosol. The newly proposed subgroup of Histic Humitropept enabled classification and correct interpretations about the behavior of the soil. The soil was basically a Humitropept but exceeds the required organic carbon content for Humitropepts as stipulated in the U. S. Comprehensive Classification System.

Correlation Between Genesis and Classification

Because soils of Western Samoa have parent material of different age and occur in various climatic zones, they provide an excellent opportunity to relate genesis to classification. A summary of the changes in classification found in soils located in the lowlands, foothills, and uplands is in Fig. 21. Soils of the lowlands generally begin formation as Lithic Entropepts. Higher rainfall in the foothills causes leaching of bases and a decrease base saturation. As a result the soils become Lithic Dystropepts. Depending on the intensity of weathering, the soils may become Typic Dystropepts if the solum is greater than 20 inches and the cation exchange capacity is less than 24 meq/100g. In either case the soil eventually becomes an Oxic Dystropept.

Depending on erosion, the lowland and foothill soils can

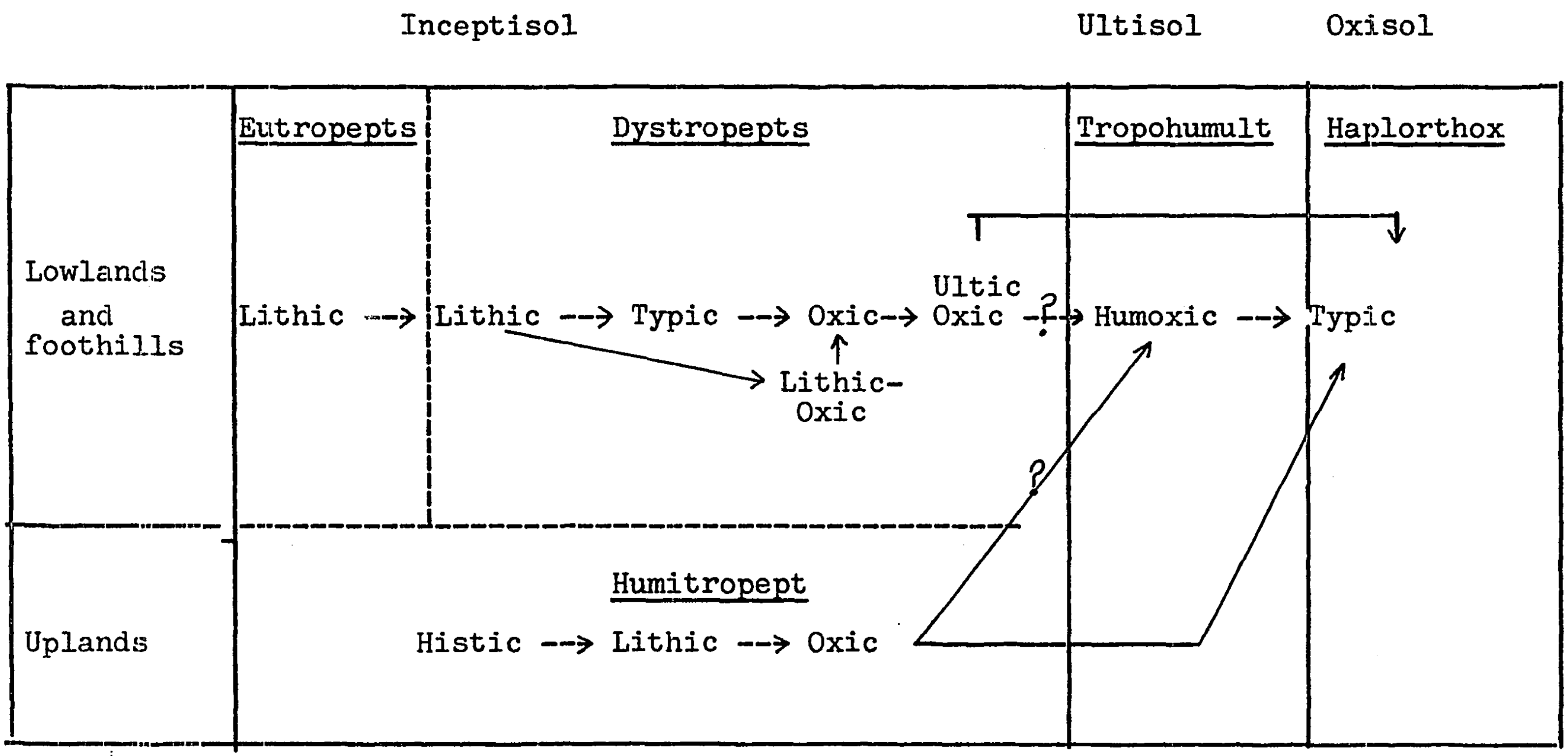


FIGURE 21. SUMMARY OF THE GENESIS OF THE MAJOR WESTERN SAMOA SOILS

develop directly to Oxisols on relatively stable surfaces or develop toward an Ultisol on unstable surfaces. The soils of the uplands tend to accumulate large quantities of organic matter so that a proposed subgroup of Histic Humitropepts is needed. Upon further weathering Lithic and Oxic Humitropepts are formed. The soils eventually weather to Oxisols.

Correlation of Western Samoa Soils and Hawaiian Soils

The Western Samoa soils generally showed weaker horizonization, higher amounts of organic matter and fresh rock material, and shallower depth than comparable Hawaiian soils located on the islands of Maui or Hawaii. The Kealakekua series on the island of Hawaii compares very well with the Salega series on Savai'i. The main difference between these two series is the apparent higher organic matter content in the Salega series.

The Makaalae series (Typic Humitropept) on the island of Maui is comparable to the Mauga series on Savai'i, the main difference being that the Mauga soil has a considerably higher organic matter content than the Makaalae soil. The Makaalae series occurs in an area with rainfall of 60 to 90 inches per year while Mauga occurs in an area with a rainfall of 175 to 200 inches per year.

The Kehena series on the island of Hawaii is similar to the Atu series. The Kehena series is more acid and thixotropic than the Atu series which has more organic matter, particularly in the surface horizon. The Kehena series is classified as an Aeric Andaquept, but the Atu series is classified as a Histic Andaquept.

The only series classified as an oxic Dystropept (fine, oxidic, isohyperthermic family) in Hawaii, is the Hanamaulu series. This series differs in many ways from the Oxic Dystropepts in Western Samoa. The Hanamaulu series is generally deeper (3 to 6 feet), contains fewer stones in the profile and has a stronger structure than the Oxic Dystropepts of Western Samoa. Although there are distinct differences, it is expected that in comparable climatic zones the behavior of the Oxic Dystropepts in Western Samoa and the Hanamaulu series would be similar.

The Oxic Humitropepts on Hawaii tend to differ from those in Western Samoa. The Oxic Humitropepts in Hawaii occur mainly on alluvial fans and terraces and in rainfall areas of 40 to 150 inches per year on Kauai. The Lanai series on Kauai apparently approaches some of the Humitropepts in Western Samoa more closely than any other Hawaiian Oxic Humitropept. This soil differs from those in Western Samoa by having a strong structure, firm, moist consistance, and a deep solum.

At the present stage in the development of the U. S. Comprehensive Soil Classification System, the suborder Tropept appears to be vaguely defined. More research is needed on this suborder and on all the Great Groups within this suborder.

The existance of an Ultisol in Western Samoa is questionable. The Upolu series was classified as an Ultisol on the basis of morphological features because laboratory analysis was unavailable.

The Ultisols in Hawaii have generally been developed in old alluvium, colluvium, and residuum. The soils are generally dark red brown, weak structured, have firm subsoils, are strongly acid, and have a weakly developed argillic horizon. The Upolu series has a very weakly developed argillic horizon, a dark brown color, weak structure and slight acidity. The argillic horizon, if it really exists, is very weakly developed. The Makawao series on Maui is the Tropohumult most similar to the Upolu series on Upolu.

The Oxisols, Ultisol, and Oxic-Ultic Dystropepts in Western Samoa were subdivided on the basis of the landform of the Fagaloa volcanics. Oxisols occurred on stable landforms, Ultisols on semistable landforms, and Oxic-Ultic Dystropepts on unstable landforms.

STATISTICAL TREATMENT

Because properties of Western Samoa soils have large variability induced by differences in climate and age of parent material, assessments can be made of the effect(s) of one variable on one or several other variables. These relationships are understandably implicit, but may be used for prediction of soil properties, and elucidation of various processes involved in the genesis of these soils.

To provide a wide range of soils, 29 additional profiles collected and analyzed by the New Zealand Soils Bureau supplemented those discussed in the previous section. The total number of horizons involved was 129. The 11 variables used in the final statistical treatment were: Soil pH, organic carbon, total nitrogen, carbon-nitrogen ratio, cation exchangeable bases of calcium, magnesium, sodium, and potassium.

Summary Statistics

Summary statistics for the 11 variables (n=129) are in table V. Examination of the minimum and maximum values indicated that selected soils represented a wide range of properties. The variability of these properties was very high as indicated by the coefficient of variation (CV) values. Soil pH had the lowest CV value of 10.1 which was expected because pH is a log function and has a restricted range. The remaining variables, with the exception of C/N ratio, had extremely high CV values. Exchangeable calcium

TABLE V. SUMMARY STATISTICS

Variable	Mean	Standard Deviation	C. V.	Skewness	Kurtosis	Minimum	Maximum
pH	5.59	0.564	10.1	-0.65	3.64^{ns}	3.8	6.7
C/N ratio	13.36	5.186	38.8	2.25**	11.44**	4.4	40.0
Organic Carbon	8.42	7.504	89.1	1.45**	4.62**	0.2	33.6
C. E. C.	35.02	25.778	73.6	1.21**	4.30**	0.9	126.5
Total Bases	13.25	21.649	163.4	3.05**	14.55**	0.0	128.3
Base Saturation	26.88	28.333	105.4	0.94**	2.70^{ns}	0.0	100.0
Exchangeable Na (meq/100g)	0.25	0.312	125.9	5.67**	46.21**	0.0	2.94
Exchangeable K (meq/100g)	0.27	0.306	114.9	2.26**	8.92**	0.0	1.80
Exchangeable Ca (meq/100g)	8.83	15.86	179.5	3.34**	16.25**	0.0	99.0
Exchangeable Mg (meq/100g)	4.08	6.415	157.4	3.70**	21.50**	0.0	46.8
Total Nitrogen	0.69	0.640	92.5	1.41**	4.53**	0.02	2.89

ns= nonsignificant

**= significant at 0.02 probability level had the highest CV at 179.5.

The highly significant skewness and kurtosis, third and fourth moments, respectively, indicated positive skewness in the majority of the variable distributions, the exception being pH. The skewness consequently limited the use of statistical analyses based on normal distribution. The means and standard deviations of skewed distributions provided unreliable estimates of central tendency and dispersion.

Population Density Functions

The quantity of research dealing with distributions of soil variables is small. Gardner (1956) represented soil aggregate-size distributions by a lognormal distribution, and Jackson (1959) presented distributions of soil clay minerals in various soils. In the geological sciences, Krumbein and Graybill (1955) presented several population density functions to describe distributions of geologic variables. These density functions were (1) normal density function, (2) log-normal density function, and (3) gamma density function.

In this study, answers to the following questions were sought. (1) What are the types of population densities that best describe the distribution of each variable, (2) what are the parameters of these distributions, and (3) what is the "goodness of fit" of each estimated population density? The population was defined as all horizons developed in residuum from basic basaltic material in Western Samoa. This description included all forms of basaltic material, all climatic regions, and all ages of parent material except recent lava flows.

Theory

Normal Density Function

The formula for the normal density function is:

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(1/2\sigma^2)(x-\mu)^2}$$

where x is a continuous variable from -00 to +00. The two parameters u and σ are the mean and standard deviation of the population, respectively. By standardization of the data, the normal density function becomes a special case, the standard normal density represented by:

$$F(z) = \frac{1}{\sqrt{2\pi}} e^{-(z^2/2)}$$

where $z = (x-u)/\sigma$ and varies from $-00 < z < +00$. The mean (u_z) is zero and the standard deviation (σ_z) is one.

Integration of f(z) from -00 to +00 results in a value of one. Integration from z_i to z_j results in the probability of standard variables occurring in the interval z_i and z_j.

Lognormal Density Function

The formula for the lognormal density function is:

$$F(x_L) = \frac{1}{\sigma_{x_L}\sqrt{2\pi}} e^{-(1/2\sigma^2_{x_L})(x_L - \mu_{x_L})^2}$$

where x is a continuous variable greater than zero and x_L is its respective logarithm. The two parameters u_{x_L} and σ_{x_L} represent the mean and standard deviation of the logarithm of x, respectively. Synonyms for these two parameters are the geometric mean (Mg) and the geometric standard deviation (σg) (Gardner, 1965).

<u>Gamma Density Function</u>

The gamma density function (Pearson Type III distribution) formula is:

$$F(g) = \frac{X^{r-1} e^{-X/B}}{\Gamma(r)\, B^r}$$

The two parameters r and B are estimated by maximum likelihood procedures (Greenwood, 1960; Krumbein, 1965; Siddiqui, 1963) outlined below.

1) Calculation of the arithmetic and geometric means:

$$A = \frac{\sum^{n} X_i}{n}$$

$$G = \sqrt[n]{X_1 \cdot X_2 \cdot X_3 \cdots X_n} \quad \text{or} \quad \text{Antilog} \frac{\sum^{n} \log X_i}{n}$$

2) Calculation of y:

y = LnA - Ln G

3) Estimation of r through the use of polynomial approximations:

a) If 0 y 0.5772

$$r = y^{-1}(0.5000876 + 0.1648852y - 0.054427y^2)$$

maximum error = 0.0088%

b) If 0.5772 y 17.0

$$r = \frac{8.898919 + 9.059950y + 0.9775373y^2}{y(17.7928 + 11.968477y + y^2)}$$

4) Estimation of B by: B = A/r

If a variable is a true gamma variate, the parameters r and B can estimate the mean and standard deviation of x by:

$$\hat{\bar{x}} = rB \qquad \hat{\sigma}^2 = B^2 r$$

Integration of f(g) from 0 to +00 results in a value of one. Therefore, integration of f(g) from x_i to x_j, where $x \geq 0$, results in the probability of a value of x occurring in that interval. The computer program given in Appendix II calculates the parameters of r and B and the probabilities of x occurring in specified class intervals.

Results and Discussion

Soil pH was the only variable of those examined that followed a normal distribution (Fig. 22). The "goodness of fit" (χ^2) test for comparing the standardized pH values to the standard normal density function resulted in a non-significant χ^2 value (19.43, df = 14) at the 0.01 level of probability.

Percent organic carbon, percent total nitrogen and exchangeable potassium followed lognormal distributions (Table VI). Frequency histograms for the original and transformed data for these variables are in Figs. 23 to 28. In examining the distributions, the author made no distinction between surface and subsurface horizons. It appears that in general the vertical distribution of organic matter in the soil profile, as compared to differences in organic matter between soils, exerts the most profound influence upon the overall distribution. Exchangeable potassium correlated strongly with total nitrogen (0.853) and, therefore, followed a similar distribution.

A gamma density function also described the distribution of percent organic carbon. The χ^2 value for the gamma density function was 50% higher than that resulting from the lognormal density function.

The gamma density function represented the distributions of cation exchange capacity, total bases, exchangeable calcium and magnesium, and carbon-nitrogen ratio. Results

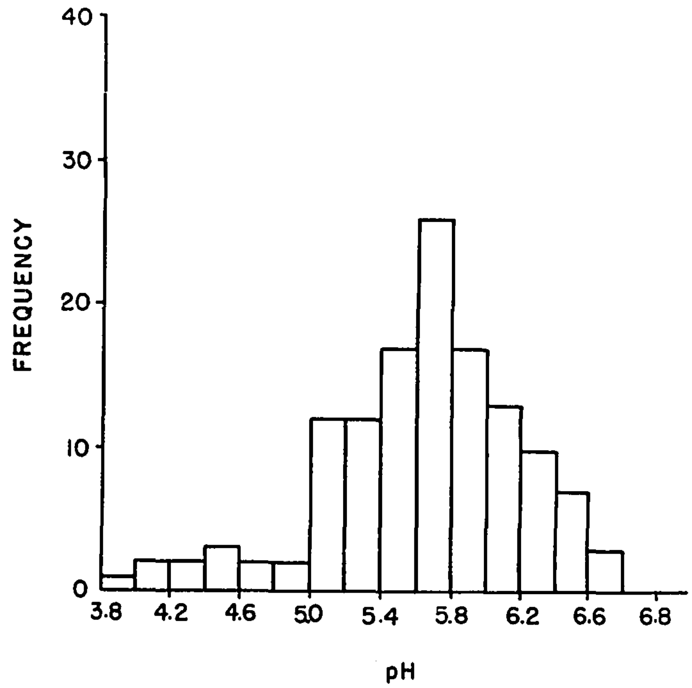


FIGURE 22. FREQUENCY HISTOGRAM FOR pH

TABLE VI. CHI-SQUARE VALUES AND PARAMETERS FOR THE LOGNORMAL DISTRIBUTIONS

Variable	Mean	Standard Deviation	Chi-Square Value	Df
Log % Organic Carbon	0.7411	0.4461	13.32^{ns}	11
Log % Nitrogen	-0.3608	0.4591	17.07^{ns}	15
Log Exchangeable Potassium (meq/100g)	-0.8254	0.5031	9.90^{ns}	13

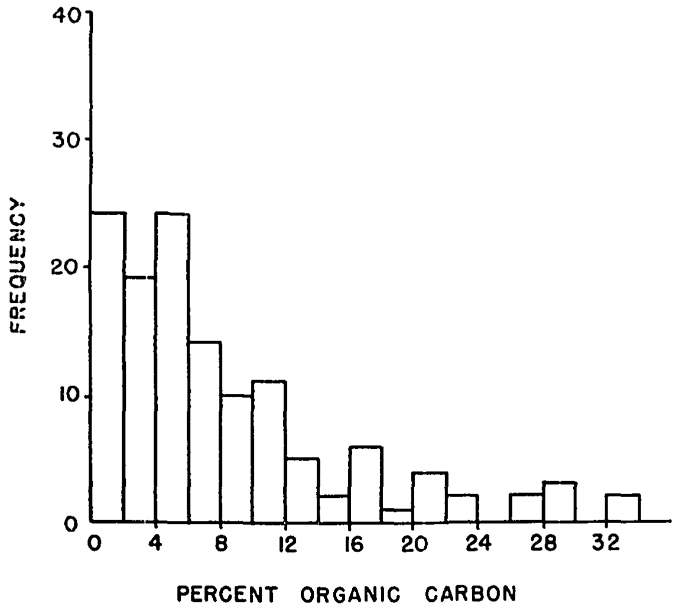


FIGURE 23. FREQUENCY HISTOGRAM FOR PERCENT ORGANIC CARBON

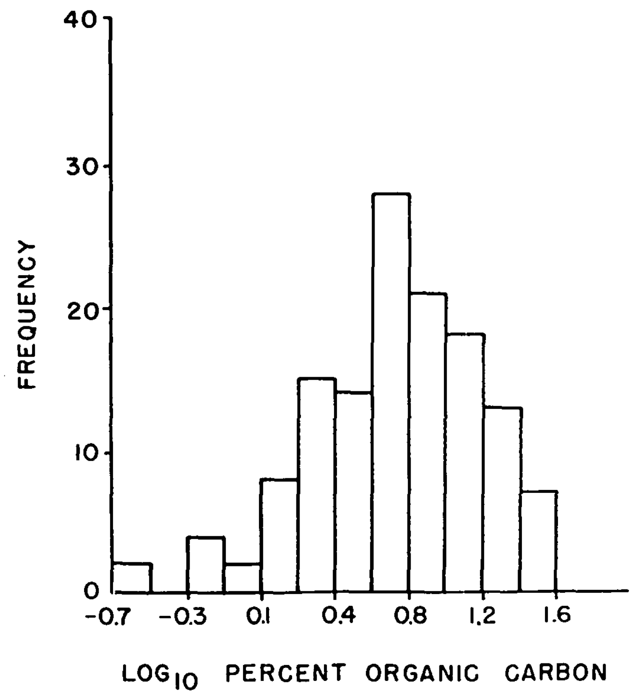


FIGURE 24. FREQUENCY HISTOGRAM FOR THE LOGARITHMS OF PERCENT ORGANIC CARBON

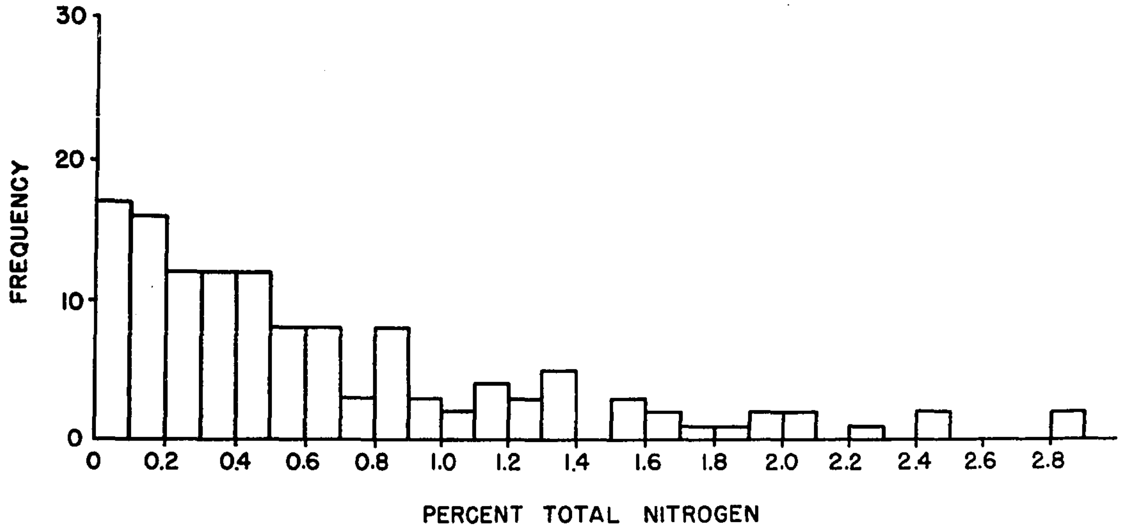


FIGURE 25. FREQUENCY HISTOGRAM FOR PERCENT TOTAL NITROGEN

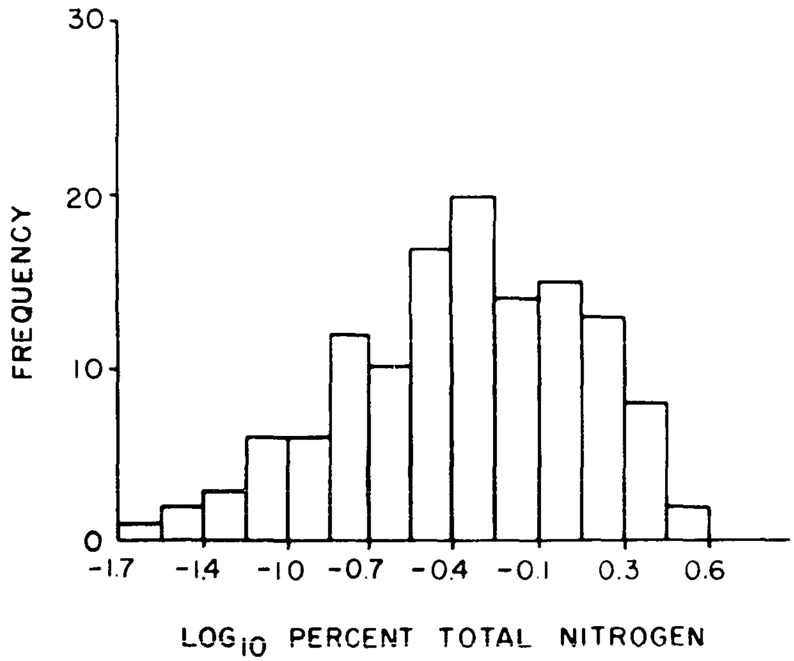


FIGURE 26. FREQUENCY HISTOGRAM FOR THE LOGARITHMS OF PERCENT TOTAL NITROGEN

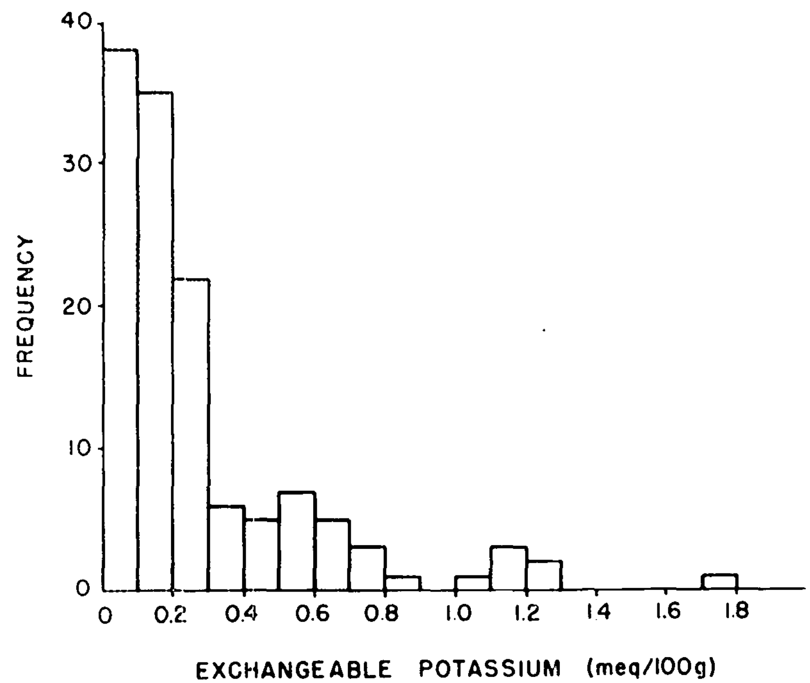


FIGURE 27. FREQUENCY HISTOGRAM FOR EXCHANGEABLE POTASSIUM

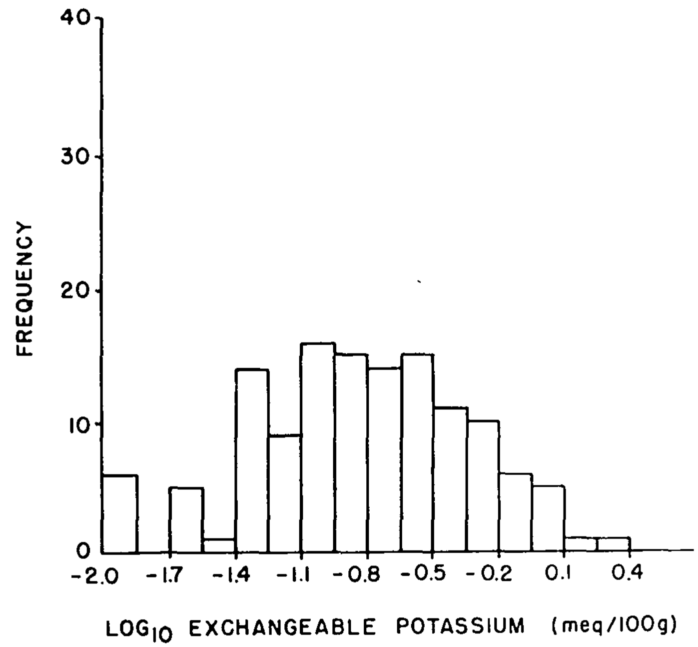


FIGURE 28. FREQUENCY HISTOGRAM FOR THE LOGARITHMS OF EXCHANGEABLE POTASSIUM

of fitting the gamma density function are in Table VII. Figures 29 to 38 give the frequency histograms of the variables and the plots of their respective gamma density functions. Table VIII gives the accumulative probabilities.

The distributions of cation exchange capacity, total bases, exchangeable calcium and magnesium were indicative of the weathering environment. Most of the soils in Western Samoa are highly leached and weathered except those soils on recent lava flows and those in the driest climatic zones. The distributions were, therefore, greatly skewed toward the lower values.

The distribution of base saturation could not be represented by the density functions discussed above. From examination of the frequency histogram for base saturation (Fig. 39) it appeared that the highest frequency occurred between 0 and 5 meq/100g, but the distribution of high base saturation values appeared relatively uniform. Base saturation, since it is a ratio, was an erratic variable. Soils with low cation exchange capacities and small amounts of total bases can have a high base saturation.

From examination of all the distributions, it was generally apparent that those variables that were highly correlated (see Table XI) had the same type of distribution. The only exception occurred with cation exchange capacity and carbon-nitrogen ratio. Cation exchange capacity correlated with total bases. Carbon-nitrogen ratio did not

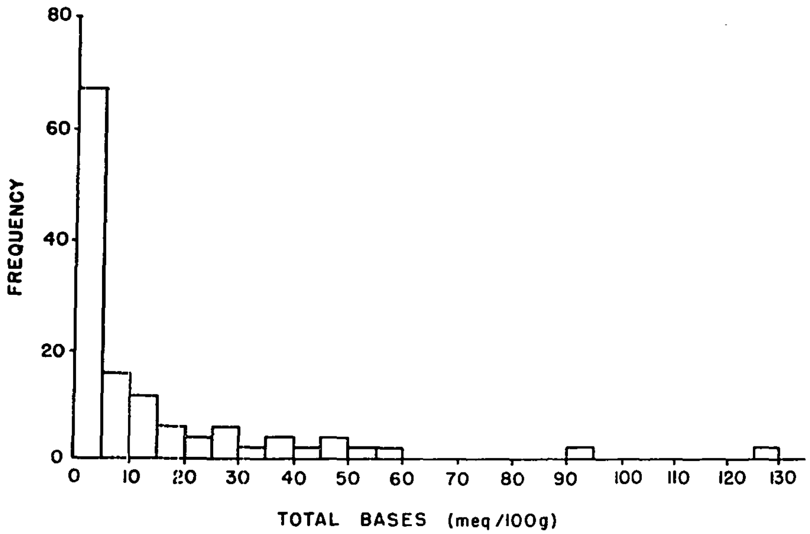


FIGURE 29. FREQUENCY HISTOGRAM FOR TOTAL BASES

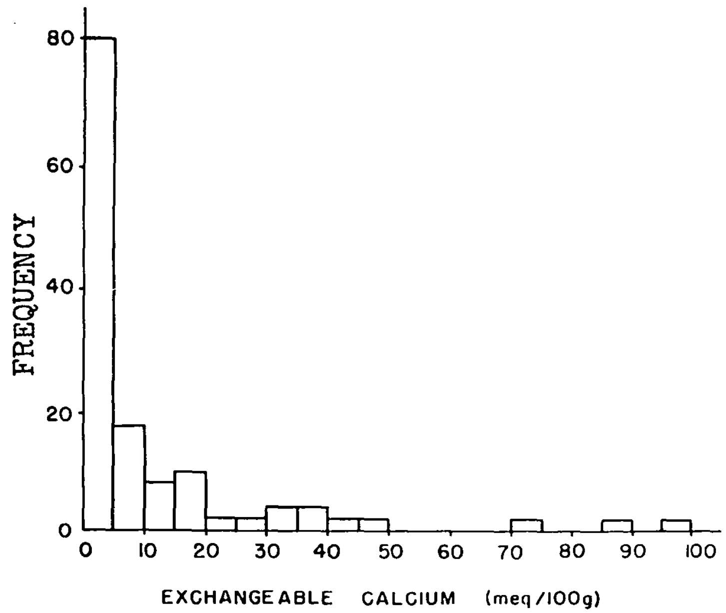


FIGURE 30. FREQUENCY HISTOGRAM FOR EXCHANGEABLE CALCIUM

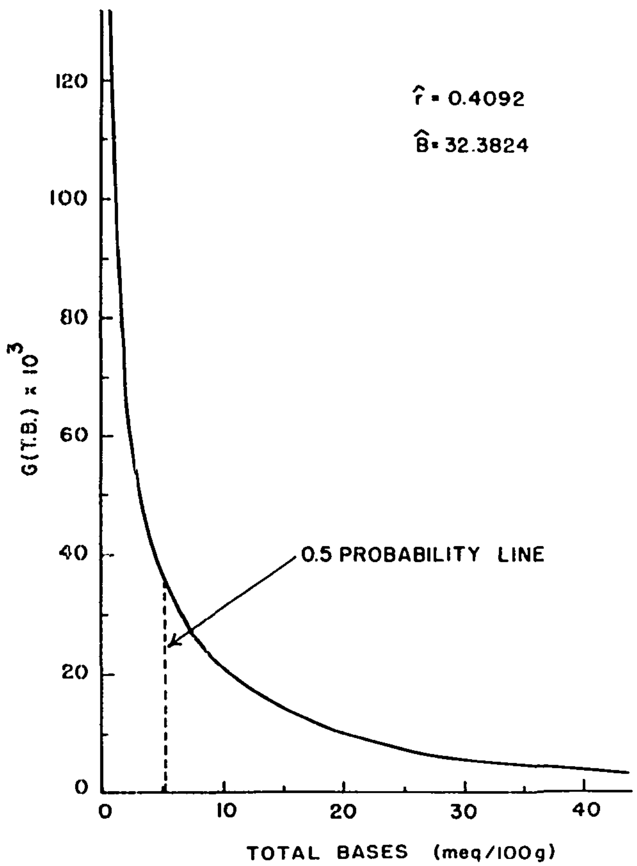


FIGURE 31. GAMMA POPULATION DENSITY FUNCTION FOR TOTAL BASES

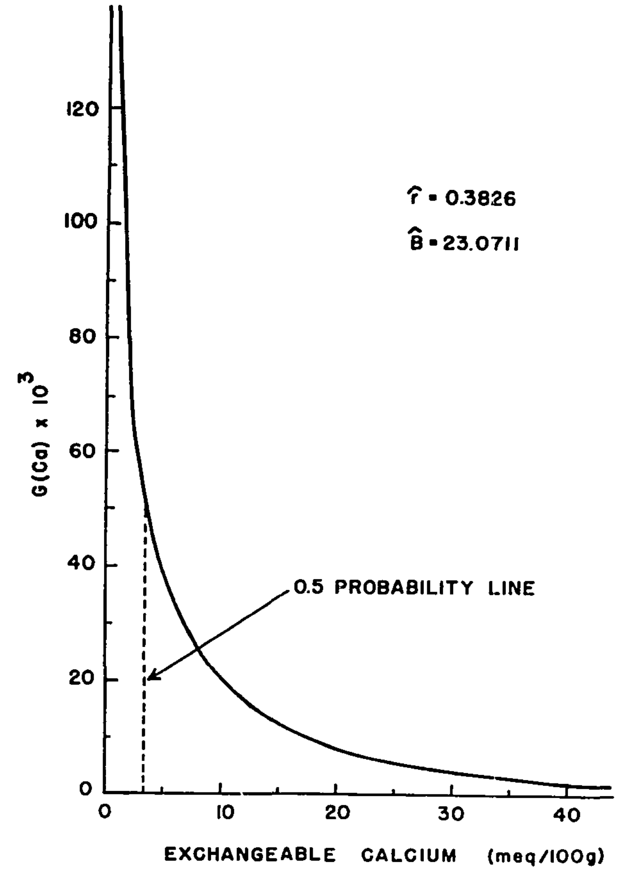


FIGURE 32. GAMMA POPULATION DENSITY FUNCTION FOR EXCHANGEABLE CALCIUM

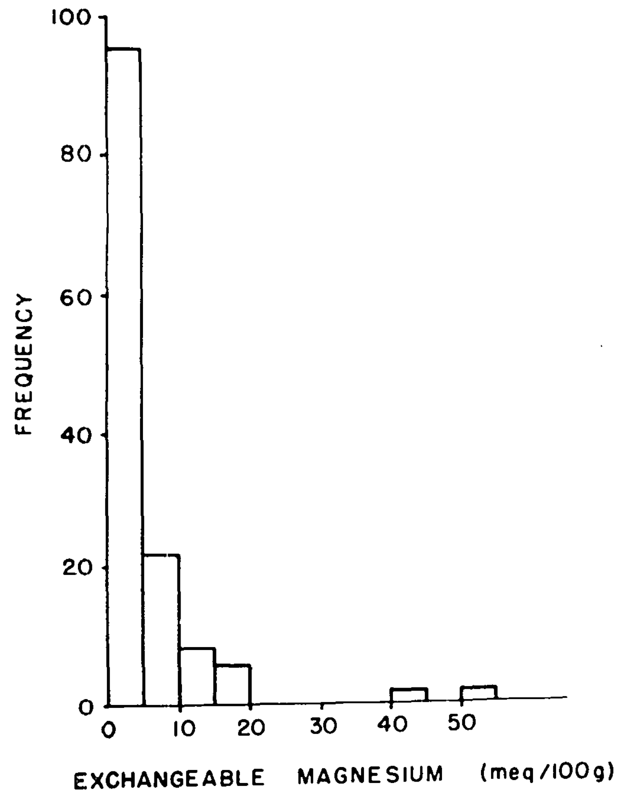


FIGURE 33. FREQUENCY HISTOGRAM FOR EXCHANGEABLE MAGNESIUM

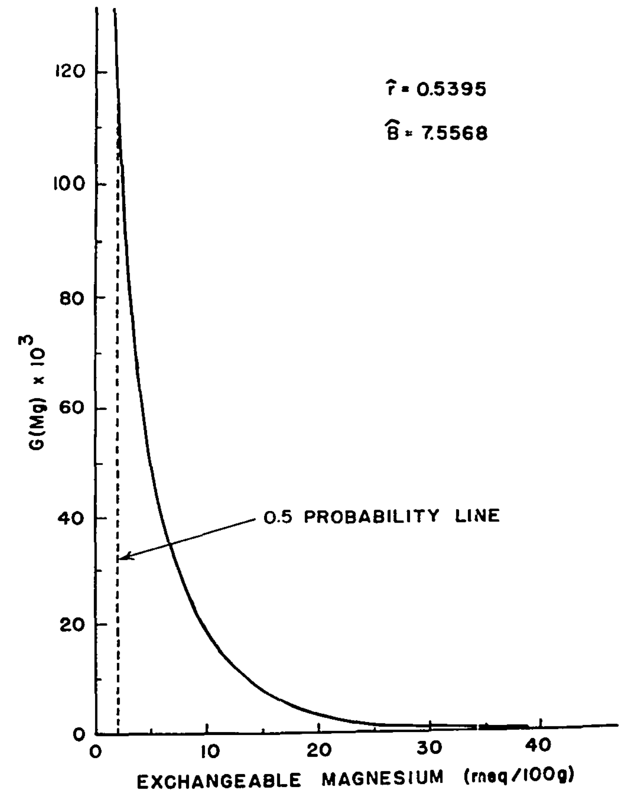


FIGURE 34. GAMMA POPULATION DENSITY FUNCTION FOR EXCHANGEABLE MAGNESIUM

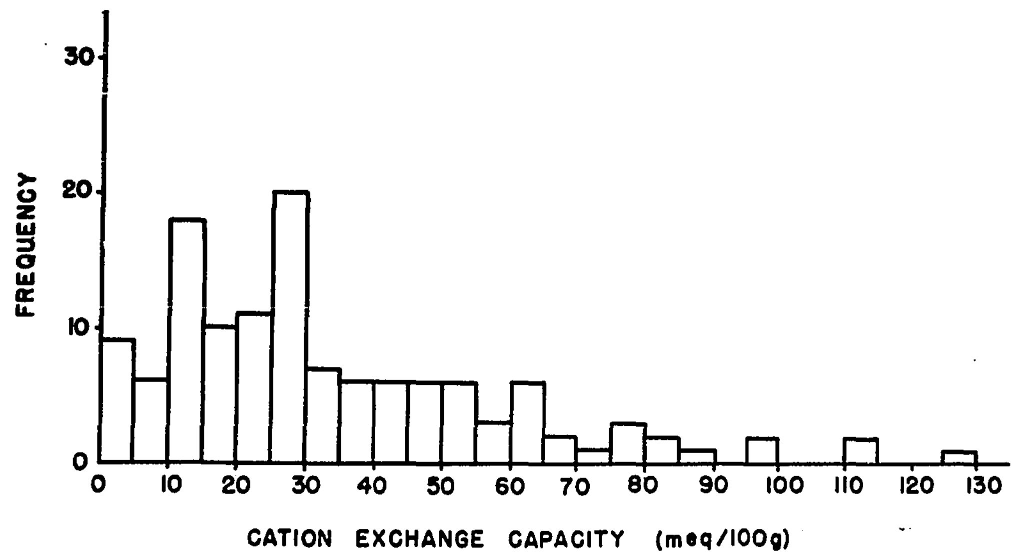


FIGURE 35. FREQUENCY HISTOGRAM FOR CATION EXCHANGE CAPACITY

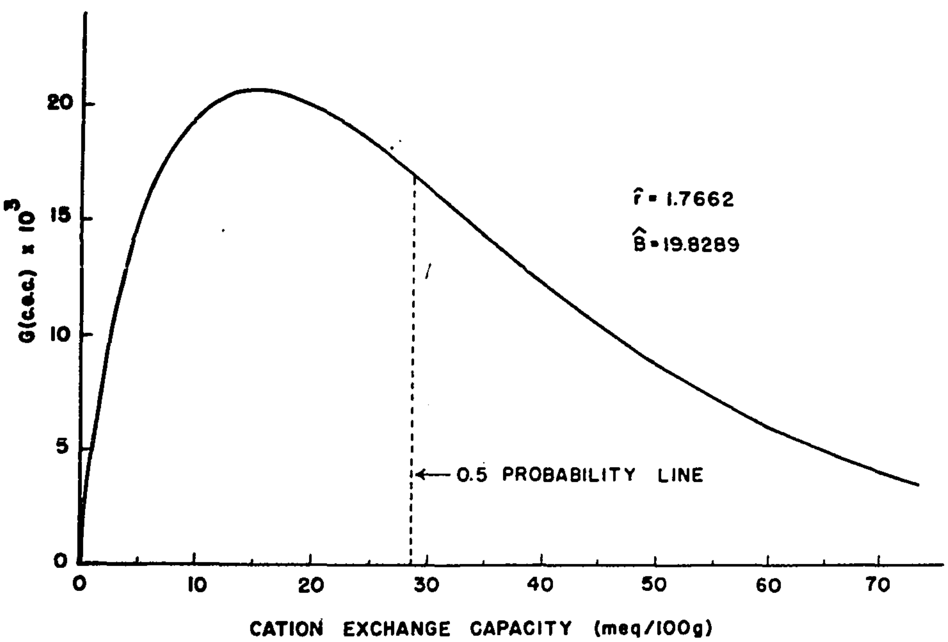


FIGURE 36. GAMMA POPULATION DENSITY FUNCTION FOR CATION EXCHANGE CAPACITY

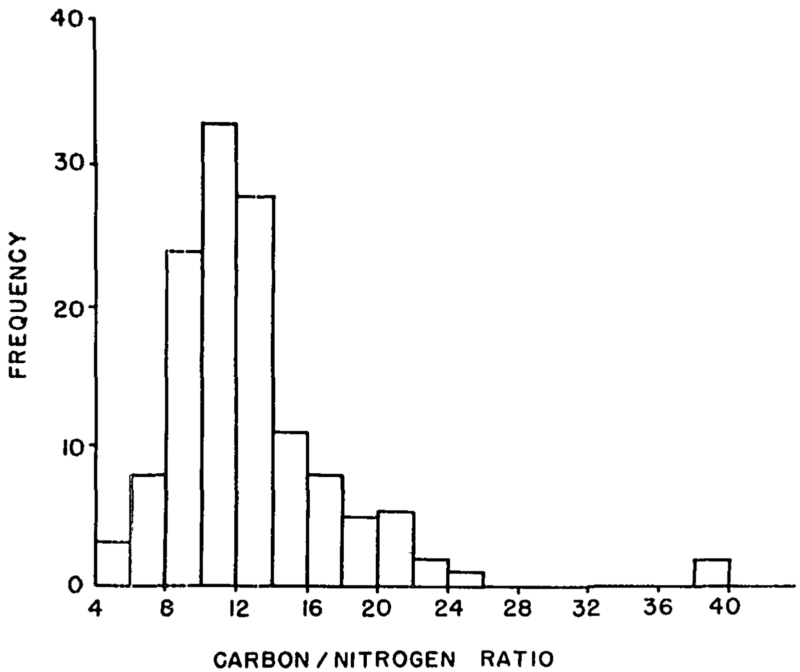


FIGURE 37. FREQUENCY HISTOGRAM FOR CARBON--NITROGEN RATIO

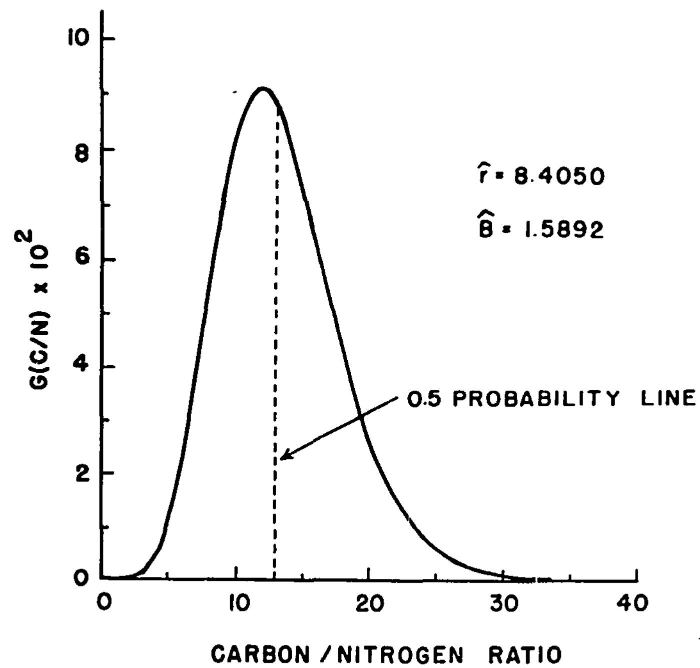


FIGURE 38. GAMMA POPULATION DENSITY FUNCTION FOR CARBON-NITROGEN RATIO

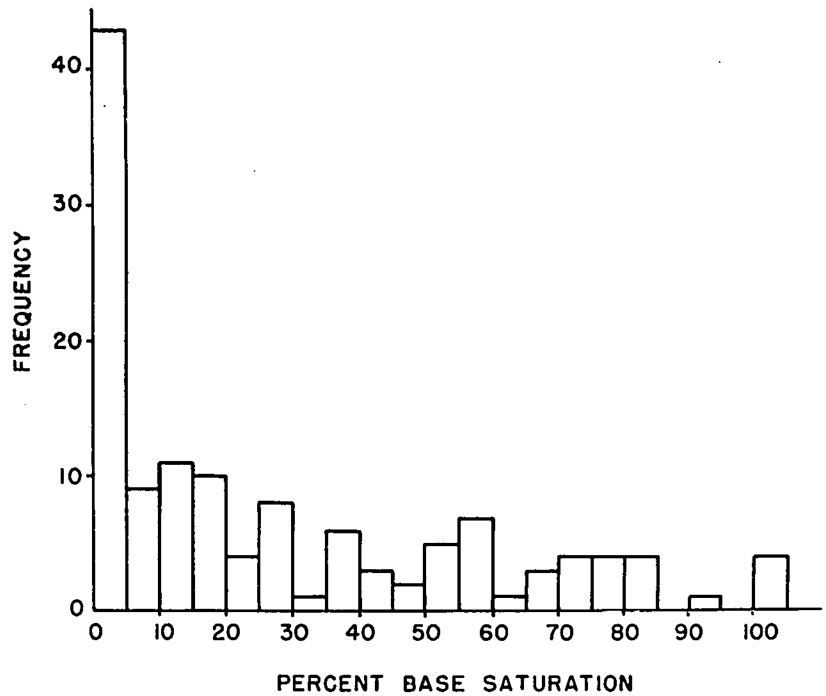


FIGURE 39. FREQUENCY HISTOGRAM FOR PERCENT BASE SATURATION

TABLE VII. CHI-SQUARE VALUES AND PARAMETERS FOR THE FITTED GAMMA DENSITY FUNCTIONS

Variable	X^2	df	r	B
Cation Exchange capacity	20.94^{ns}	19	1.7662	19.8290
Total Bases	11.28^{ns}	12	0.4092	32.3824
Exchangeable Ca	8.20^{ns}	19	0.3826	23.0711
Exchangeable Mg	1.69^{ns}	4	0.5395	7.5568
C/N Ratio	13.33^{ns}	11	8.4050	1.5892

correlate with any other variable. Its distribution appeared to be between a normal and a lognormal distribution.

<u>Testing Assumptions of Normality</u> The assumption of normality in analysis of variance models must be met so that the validity of tests of significance remains unaffected. Cochran (1947) stated that if the population distributions are slightly skewed, the consequences in analysis of variance models are not serious. If the distributions are greatly skewed, however, the original data requires transformation producing normal distribution. The consequence of non-normality is that the test of significance may show the "effects" significant where there is no significance.

<u>Measures of Central Tendency</u> The use of probabilities derived from the population density function ascertained true measures of central tendency. The arithmetic mean of exchangeable calcium was 8.83, but the value of exchangeable calcium at 0.5 probability (Table IX) was 3.2. The definition of 0.5 probability (or 0.5 percentage point) is $\int_{0}^{x_i} f(g) = 0.5$ which means that 50 percent of the population values for exchangeable Ca was $\leq$ 3.2 meq/100g and the remaining 50 percent was $\geq$ 3.2 meq/100g. It is apparent that the 0.5 probability value is definitely a better measure of central tendency than the arithmetic mean.

TABLE VIII. ACCUMULATIVE PROBABILITIES

Exchangeable Ca (meq/100g)			Exchangeable Mg (meq/100g)			Total Bases (meq/100g)		
	.0	.5		.0	.5		.0	.5
0	0.0000	0.2419	0	0.0000	0.2495	0	0.0000	0.1932
1	0.3183	0.3722	1	0.3566	0.4350	1	0.2588	0.3060
2	0.4149	0.4506	2	0.4978	0.5500	2	0.3440	0.3762
3	0.4814	0.5087	3	0.5946	0.6332	3	0.4043	0.4294
4	0.5330	0.5551	4	0.6670	0.6969	4	0.4521	0.4728
5	0.5753	0.5938	5	0.7235	0.7472	5	0.4920	0.5097
6	0.6110	0.6269	6	0.7685	0.7877	6	0.5263	0.5418
7	0.6418	0.6558	7	0.8050	0.8207	7	0.5564	0.5702
8	0.6689	0.6812	8	0.8350	0.8480	8	0.5833	0.5957
9	0.6928	0.7038	9	0.8598	0.8705	9	0.6075	0.6187
10	0.7142	0.7241	10	0.8804	0.8894	10	0.6294	0.6397
11	0.7335	0.7424	11	0.8976	0.9052	11	0.6495	0.6589
12	0.7509	0.7590	12	0.9121	0.9185	12	0.6679	0.6766
13	0.7668	0.7742	13	0.9243	0.9297	13	0.6849	0.6929
14	0.7813	0.7880	14	0.9346	0.9392	14	0.7006	0.7081
15	0.7945	0.8008	15	0.9434	0.9473	15	0.7153	0.7222
16	0.8067	0.8125	16	0.9508	0.9541	16	0.7289	0.7354
17	0.8180	0.8232	17	0.9571	0.9600	17	0.7417	0.7478
18	0.8283	0.8332	18	0.9625	0.9649	18	0.7536	0.7593
19	0.8379	0.8425	19	0.9671	0.9692	19	0.7648	0.7702
20	0.8468	0.8510	20	0.9711	0.9728	20	0.7754	0.7804
21	0.8551	0.8590	21	0.9745	0.9760	21	0.7853	0.7900
22	0.8628	0.8664	22	0.9773	0.9786	22	0.7946	0.7991
23	0.8699	0.8733	23	0.9798	0.9809	23	0.8035	0.8077
24	0.8766	0.8798	24	0.9820	0.9829	24	0.8118	0.8158
25	0.8828	0.8858	25	0.9838	0.9846	25	0.9197	0.8235
26	0.8886	0.8914	26	0.9854	0.9861	26	0.8971	0.8307

TABLE VIII. (Continued) ACCUMULATIVE PROBABILITIES

	Cation Exchange Capacity (meq/100g)					C/N Ratio	
	.0	.5		.0	.5		.0	.5
0	0.0000	0.0009	27	0.4708	0.4796	0	0.0000	0.0000
1	0.0030	0.0061	28	0.4883	0.4969	1	0.0000	0.0000
2	0.0100	0.0146	29	0.5055	0.5139	2	0.0000	0.0001
3	0.0198	0.0256	30	0.5222	0.5304	3	0.0004	0.0011
4	0.0320	0.0387	31	0.5385	0.5465	4	0.0026	0.0054
5	0.0459	0.0535	32	0.5544	0.5622	5	0.0100	0.0170
6	0.0614	0.0696	33	0.5699	0.5775	6	0.0270	0.0406
7	0.0782	0.0869	34	0.5850	0.5924	7	0.0581	0.0798
8	0.0959	0.1051	35	0.5997	0.6068	8	0.1057	0.1358
9	0.1145	0.1241	36	0.6139	0.6209	9	0.1697	0.2071
10	0.1338	0.1436	37	0.6277	0.6345	10	0.2474	0.2900
11	0.1535	0.1636	38	0.6412	0.6478	11	0.3342	0.3795
12	0.1737	0.1839	39	0.6542	0.6606	12	0.4251	0.4704
13	0.1941	0.2044	40	0.6669	0.6730	13	0.5149	0.5581
14	0.2147	0.2251	41	0.6791	0.6891	14	0.5995	0.6390
15	0.2354	0.2458	42	0.6910	0.6968	15	0.6762	0.7109
16	0.2561	0.2664	43	0.7025	0.7081	16	0.7432	0.7728
17	0.2768	0.2870	44	0.7136	0.7190	17	0.7999	0.8245
18	0.2973	0.3075	45	0.7224	0.7296	18	0.8467	0.8666
19	0.3177	0.3278	46	0.7348	0.7398	19	0.8843	0.9001
20	0.3379	0.3479	47	0.7448	0.7497	20	0.9140	0.9262
21	0.3578	0.3677	48	0.7546	0.7593	21	0.9369	0.9462
22	0.3775	0.3872	49	0.7640	0.7685	22	0.9543	0.9612
23	0.3968	0.4064	50	0.7730	0.7775	23	0.9672	0.9724
24	0.4158	0.4252	51	0.7818	0.7861	24	0.9768	0.9805
25	0.4345	0.4437	52	0.7903	0.7944	25	0.9837	0.9864
26	0.4528	0.4618	53	0.7984	0.8024	26	0.9887	0.9906

TABLE IX. COMPARISON OF ARITHMETIC MEANS AND VALUES AT THE 0.5 PROBABILITY FOR GAMMA VARIATES

	Arithmetic Mean	0.5 Probability
Cation Exchange Capacity (meq/100g)	35.02	28.6
Total Bases (meq/100g)	13.25	5.2
Carbon-Nitrogen Ratio	13.36	13.0
Exchangeable Calcium (meq/100g)	8.83	3.2
Exchangeable Magnesium (meq/100g)	4.08	2.0

Harter (1969) presented new tables of percentage points for Pearson Type III distributions whereby one can calculate values corresponding to any probability by knowing the mean, standard deviation, and skew of a distribution. These tables enabled calculation of the values occurring at the 0.5 probability for the above gamma variates. It appeared that Harter's tables gave a slight underestimate of the 0.5 probability value compared to those derived from integration of the gamma density function. Although there is underestimation, these tables provide quick estimates of central tendency for highly skewed distributions.

Defining a Modal Soil In a soil survey, soils in a particular soil body are often related to a modal profile which is commonly defined as a profile having the average characteristics of soils occurring in this body (Cline, 1949). Presently, no satisfactory methods for determining the closeness of association of soil profiles to their modal profile have been developed. The probabilities derived from the population density functions can be used to provide this measure of association. The modal profile can be defined as a profile containing soil properties as values occurring at the 0.5 probability.

Measurement of association can be made by selecting any soil and determining the accumulative probabilities of its properties, and then by taking the mean deviation of those probabilities from the modal 0.5 probability. Several soils can be ranked from most atypical (negative mean deviation) to most typical (modal) to most atypical (positive mean deviation).

Although there were insufficient replicate samples for any one series to define a modal profile by the above procedure, the author applied this procedure to define the modal profile of all those series studied. The procedure split the soils into two groups (Table X). Those soils with negative mean deviations were all highly weathered, had low cation exchange capacity, low total bases, and low organic matter. Those soils with positive mean deviation had high amounts of organic matter, high total bases, and high cation exchange capacity. Salega, which had properties associated with both groups, was closest to the modal soil.

TABLE X. RANKING OF WESTERN SAMOA SOIL SERIES ACCORDING TO THEIR MEASURE OF ASSOCIATION WITH THE MODAL PROFILE

Soil	Measure of Association to Modal Profile
Etimuli	-0.244
Vaipouli	-0.214
Afiamalu	-0.199
Solosolo	-0.164
Moamoa	-0.160
Tiavi	-0.159
Tanumalala (B)	-0.150
Sauaga	-0.134
Fiamoe	-0.087
Tanumalala (A)	-0.060
Luatuanu'u	-0.051
Alafua	-0.047
Upolu	-0.042
Falealili	-0.019
Modal	0.000
Salega	0.013
Fagaga	0.025
Lefaga	0.140
Sataua	0.164
Saleimoa (B)	0.214
Saleimoa (A)	0.215
Mauga	0.217
Atu	0.249
Vaisala	0.322

$$\text{Measure of Association} = \frac{\sum_{i=1}^{nH} (\text{Pacc.} - 0.5)}{nH}$$

n = Number of properties H = Number of Horizons

Correlation and Regression Analyses

Introduction

Soil is an integrated system. Changes in one part of the system inevitably produce changes in another part of the system. In nature, changes in genetic factors produce these changes in the soil system. A study of these natural relationships enables simulation of them by use of implicit equations derived by means of simple and multiple regression techniques.

The correlation matrix given in Table XI indicates that a majority of the variables studied intercorrelated significantly. The correlations between many variables appeared sufficiently high that simple regression proved to be a reliable method of prediction. Because the accuracy of these predictions was within reasonable limits, the simple regression equations were used to reduce data redundancy.

Some variables could not be predicted accurately by simple regression equations. For some of these variables, multiple regression techniques were used to develop better equations. In a few cases, neither simple nor multiple regression produced adequate equations. A two independent variable multiple regression equation was generally used successfully in expressing relationships between those Western Samoa soil variables studied.

TABLE XI. CORRELATION MATRIX

2	-0.266									
3	-0.247	-0.082								
4	0.018	-0.266	0.888							
5	0.413	-0.228	0.563	0.722						
6	0.507	-0.352	0.328	0.496	0.816					
7	-0.049	-0.121	0.498	0.519	0.536	0.380				
8	-0.179	-0.171	0.834	0.783	0.653	0.495	0.666			
9	0.410	-0.218	0.541	0.697	0.975	0.773	0.481	0.608		
10	0.357	-0.208	0.474	0.605	0.828	0.750	0.567	0.592	0.690	
11	-0.119	-0.257	0.948	0.905	0.640	0.434	0.492	0.853	0.611	0.549
	1	2	3	4	5	6	7	8	9	10

TABLE XI. (Continued) CORRELATION MATRIX

Number	Variable
1	pH
2	Carbon-Nitrogen Ratio
3	Percent Organic Carbon
4	Cation Exchange Capacity (meq/100g)
5	Total Exchangeable Bases (meq/100g)
6	Percent Base Saturation
7	Exchangeable Sodium (meq/100g)
8	Exchangeable Potassium (meq/100g)
9	Exchangeable Calcium (meq/100g)
10	Exchangeable Magnesium (meq/100g)
11	Percent Total Nitrogen

$r_{0.05} = 0.174$ $r_{0.01} = 0.228$

Results and Discussion

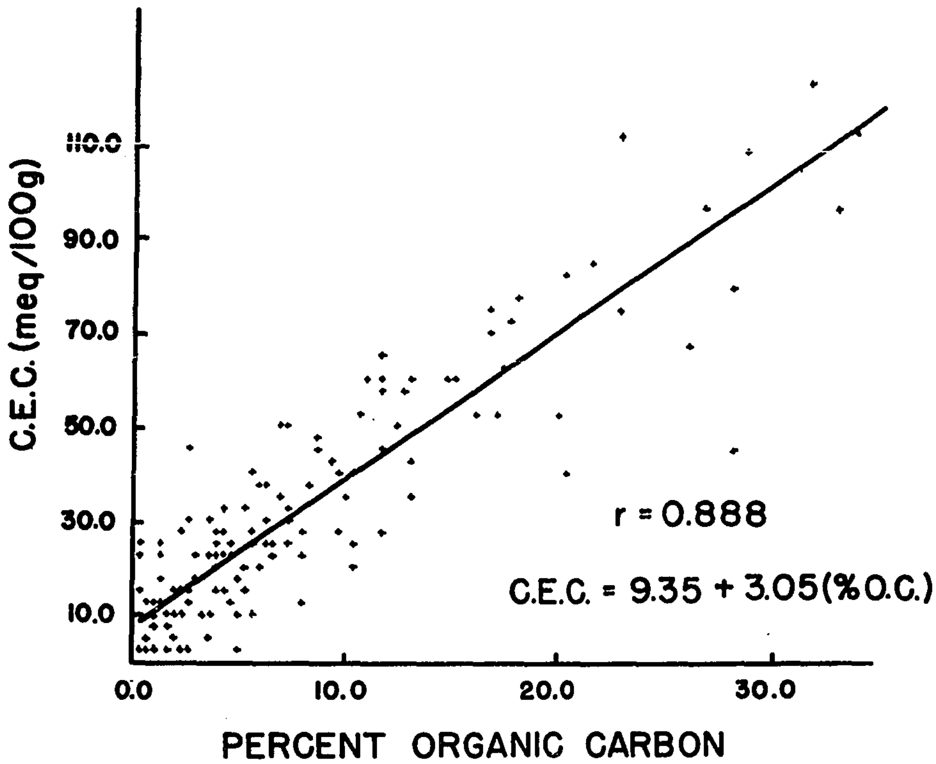
Simple Regression The relationships between variables as derived by simple regression are in Figs. 40 to 45. Percent organic carbon and cation exchange capacity correlated highly (r = 0.888). The intercept at 9.35 meq/100g (Fig.40) indicated the contribution of the inorganic fraction of the soil. Substituted into the equation, the amount of organic carbon in 100 percent organic matter (58.14) determined the contribution of the organic fraction. The result was 168 meq/100g of organic matter or 1.69 meq for one gram of organic matter. These values did not deviate greatly from the assumed cation exchange capacity for organic matter.

Percent total nitrogen (r = 0.905) had a slightly better correlation than organic carbon (r = 0.888) did with cation exchange capacity. It was apparent that the correlations were not significantly different. The intercept for nitrogen was slightly greater than that for organic carbon, but neither value differed significantly from one another. Neither of the two relationships were good predictors.

Organic carbon and total nitrogen were highly intercorrelated. The correlation between these two variables was considered sufficiently high (0.948) to use the simple regression equation to predict either total nitrogen or organic carbon.

FIGURE 40. SIMPLE REGRESSION ANALYSIS SHOWING RELATION BETWEEN PERCENT ORGANIC CARBON AND CATION EXCHANGE CAPACITY

FIGURE 41. SIMPLE REGRESSION ANALYSIS SHOWING RELATION BETWEEN PERCENT NITROGEN AND CATION EXCHANGE CAPACITY


C.E.C. (meq/100g)
110.0
90.0
70.0
50.0
30.0
10.0
0.0
10.0
20.0
30.0
PERCENT ORGANIC CARBON
r = 0.888
C.E.C. = 9.35 + 3.05(%O.C.)

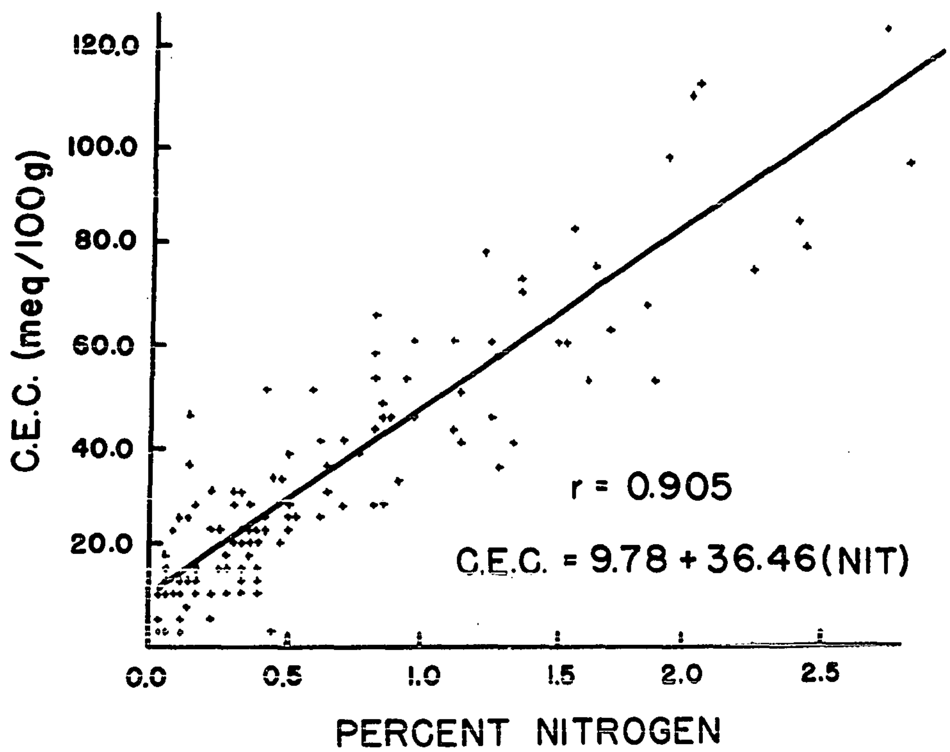
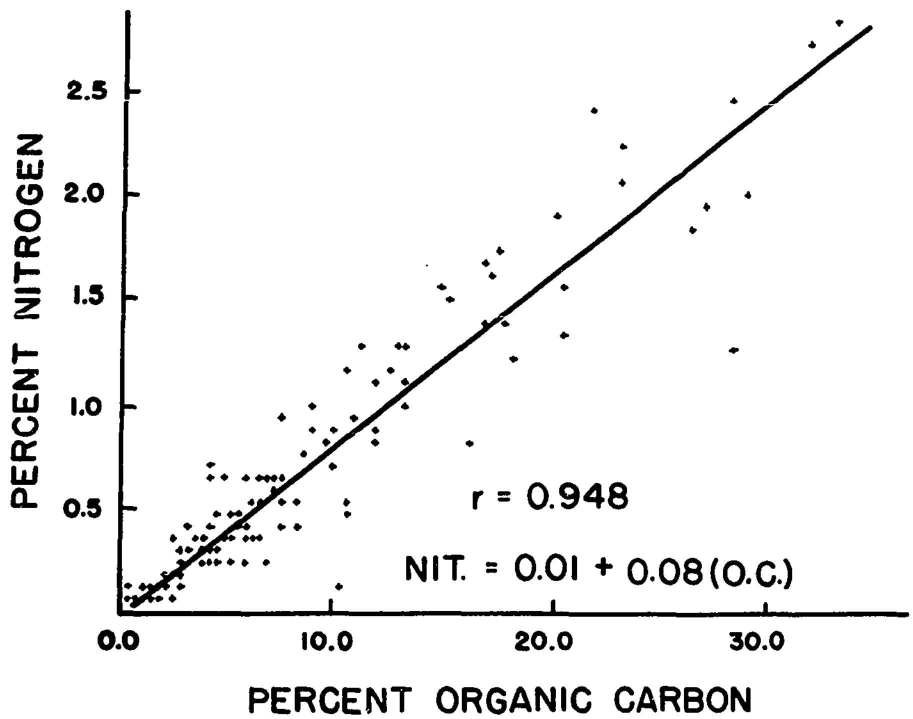
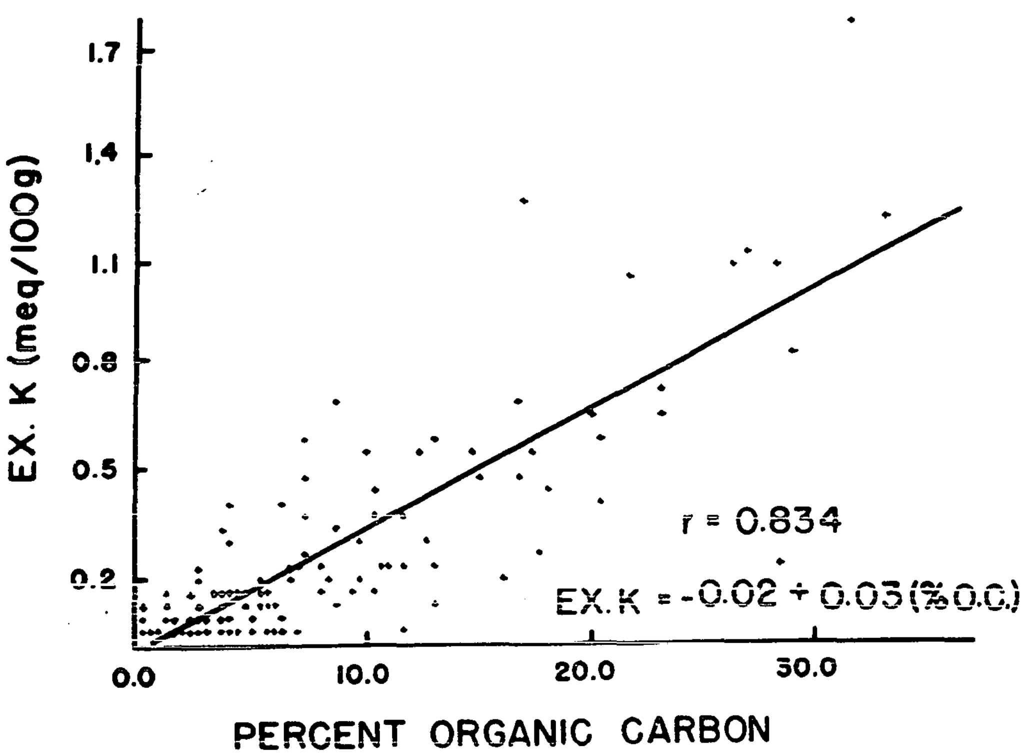

C.E.C. (meq/100g)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.5
1.0
1.5
2.0
2.5
PERCENT NITROGEN
r = 0.905
C.E.C. = 9.78 + 36.46(NIT)

FIGURE 42. SIMPLE REGRESSION ANALYSIS SHOWING RELATION BETWEEN PERCENT ORGANIC CARBON AND PERCENT NITROGEN

FIGURE 43. SIMPLE REGRESSION ANALYSIS SHOWING RELATION BETWEEN PERCENT ORGANIC CARBON AND EXCHANGEABLE POTASSIUM



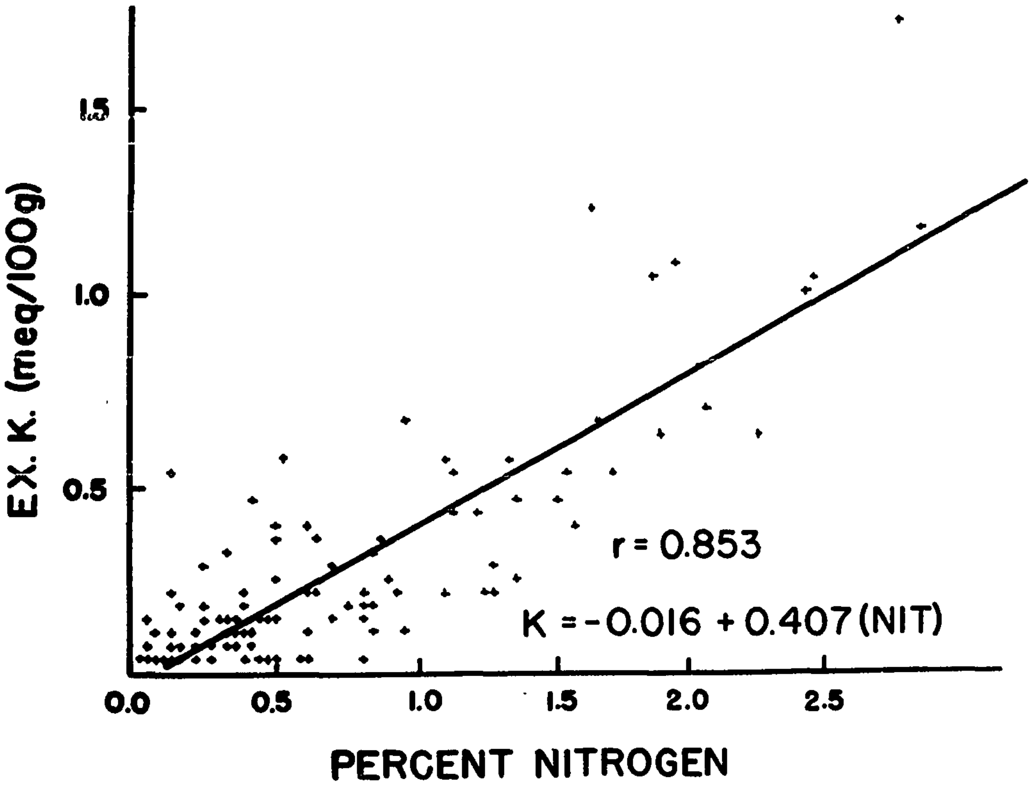
PERCENT NITROGEN
2.5
2.0
1.5
1.0
0.5
r = 0.948
NIT. = 0.01 + 0.08(O.C.)
0.0
10.0
20.0
30.0
PERCENT ORGANIC CARBON

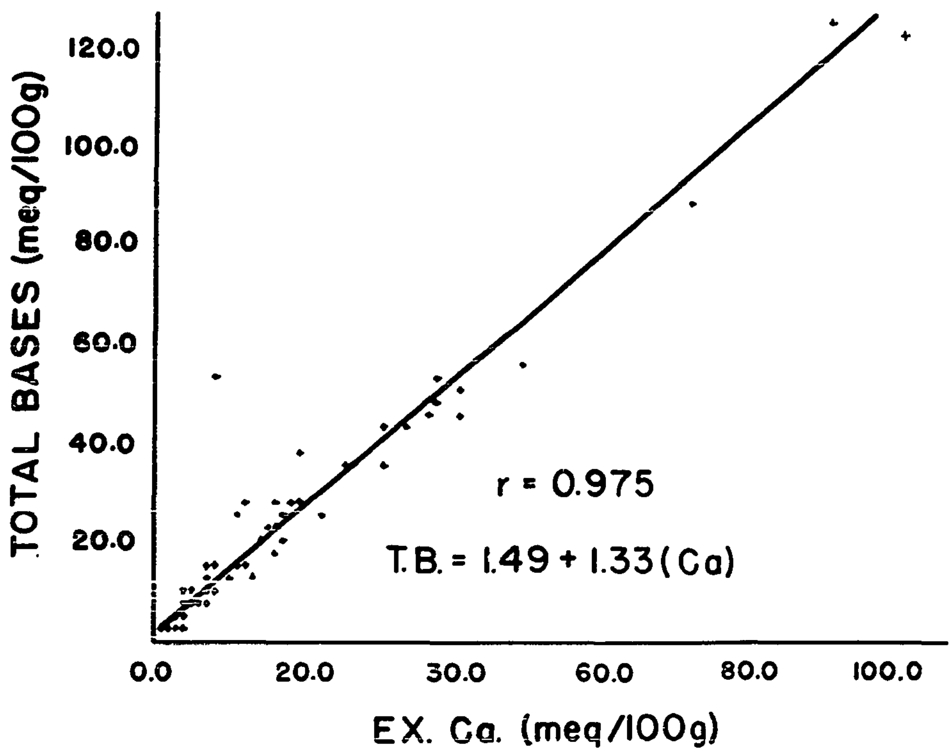


EX. K (meq/100g)
1.7
1.4
1.1
0.8
0.5
0.2
r = 0.834
EX.K = -0.02 + 0.03(%O.C.)
0.0
10.0
20.0
30.0
PERCENT ORGANIC CARBON

FIGURE 44. SIMPLE REGRESSION ANALYSIS SHOWING RELATION BETWEEN PERCENT NITROGEN AND EXCHANGEABLE POTASSIUM

FIGURE 45. SIMPLE REGRESSION ANALYSIS SHOWING THE RELATION BETWEEN EXCHANGEABLE CALCIUM AND TOTAL BASES


EX. K. (meq/100g)
1.5
1.0
0.5
r = 0.853
K = -0.016 + 0.407 (NIT)
0.0
0.5
1.0
1.5
2.0
2.5
PERCENT NITROGEN


TOTAL BASES (meq/100g)
120.0
100.0
80.0
60.0
40.0
20.0
r = 0.975
T.B. = 1.49 + 1.33 (Ca)
0.0
20.0
30.0
60.0
80.0
100.0
EX. Ca. (meq/100g)

The potassium content in most Western Samoa soils is a limiting factor in crop production. Although the correlations were not sufficient for predictive value, the correlations between exchangeable potassium and organic carbon (0.834) and between exchangeable potassium and nitrogen (0.853) suggested that soil organic matter may have a role in supplying exchangeable potassium. Organic matter content of the soil should, therefore, be maintained at a relatively high level.

The predominant exchangeable cation of all the soils studied was calcium. By measuring exchangeable calcium, one can accurately predict the total exchangeable bases in the soil as the relationship given in Fig. 45 indicates.

Since exchangeable potassium and sodium were in minute quantities, a good predictor for exchangeable magnesium was: Total bases minus exchangeable calcium. When the total bases were very high, the multiple regression equation exchangeable magnesium.

Multiple Regression The results from using multiple regression analyses are given in Table XII. Contoured regression surfaces for three of the equations are given in Fig. 46 to 48. As mentioned in the previous section, a majority of the soil variables were highly intercorrelated. Due to this high intercorrelation, use of multiple regression

TABLE XII. MULTIPLE REGRESSION EQUATIONS

(1) Cation Exchange Capacity = 10.275 + 0.288 (Total Bases) + 30.244 (Nitrogen)

R^2 = 0.8543

(2) Exchangeable Magnesium = 0.204 + 0.940 (Total Bases) - 0.973 (Exchangeable Calcium)

R^2 = 0.9684

Standard Error of the Estimate = 3.612

(3) Base Saturation = -43.319 + 10.283 (pH) + 0.957 (Total Bases)

R^2 = 0.7003

Standard Error of the Estimate = 15.633

(4) Exchangeable Potassium = -0.018 + 0.008 (Exchangeable Magnesium) + 0.361 (Nitrogen)

R^2 = 0.7490

Standard Error of the Estimate = 0.161

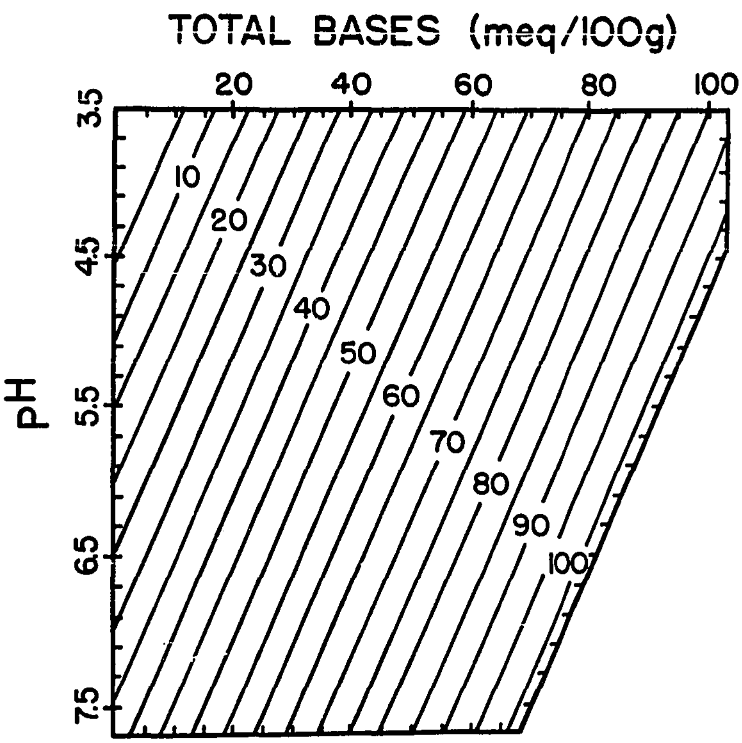
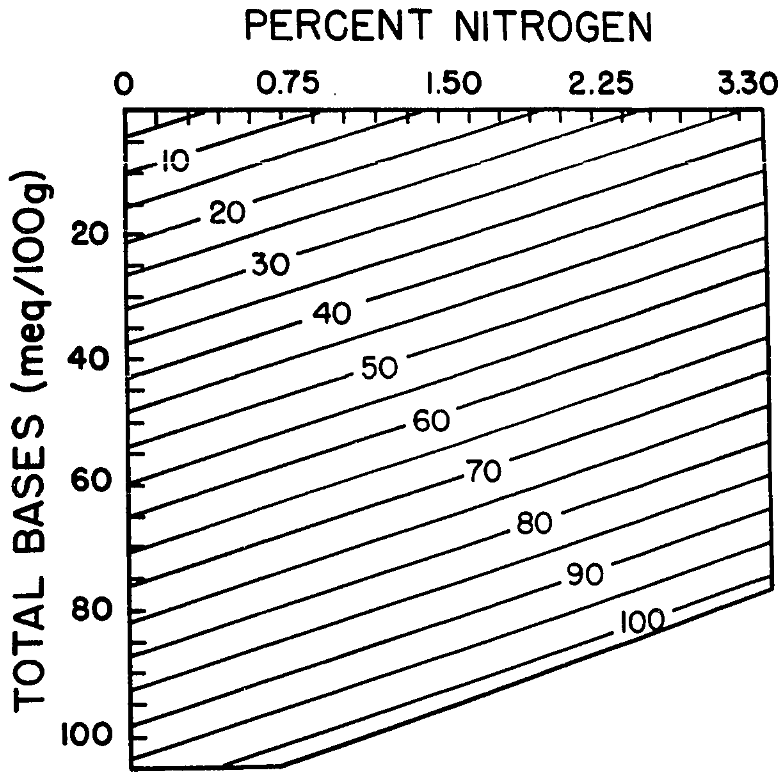
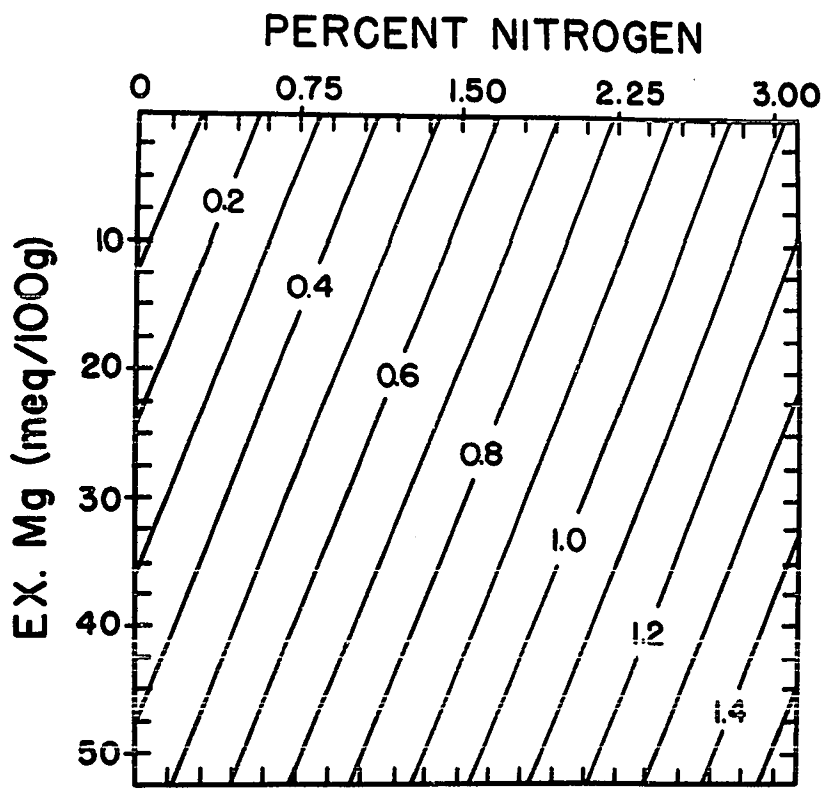


FIGURE 46. MULTIPLE REGRESSION SURFACE SHOWING RELATION BETWEEN pH (X_1), TOTAL BASES (X_2) AND BASE SATURATION (Y)

FIGURE 47. MULTIPLE REGRESSION SURFACE SHOWING RELATION BETWEEN TOTAL BASES (X_1), PERCENT NITROGEN (X_2), AND CATION EXCHANGE CAPACITY (Y)

FIGURE 48. MULTIPLE REGRESSION SURFACE SHOWING RELATION BETWEEN EXCHANGEABLE MAGNESIUM (X_1), PERCENT NITROGEN (X_2), AND EXCHANGEABLE POTASSIUM (Y)


PERCENT NITROGEN
0
0.75
1.50
2.25
3.30
TOTAL BASES (meq/100g)
20
40
60
80
100
10
20
30
40
50
60
70
80
90
100


PERCENT NITROGEN
0
0.75
1.50
2.25
3.00
EX. Mg (meq/100g)
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
1.2
1.4

techniques was often difficult. Selection of independent variables that were truly independent of each other was virtually impossible. For example, regressing organic carbon and total nitrogen on cation exchange capacity did not increase the R^2 value. Total nitrogen and organic carbon provided about equal amounts of information explaining the variance of cation exchange capacity. Total bases, although it had a lower correlation with cation exchange capacity (0.722) than organic carbon did with cation exchange capacity (0.888), was more independent of nitrogen than was organic carbon. Total bases was, therefore, a more efficient predictor of cation exchange capacity with nitrogen than organic carbon was with nitrogen. For this reason, total bases contributed a small amount of information which increased the R^2 of the multiple regression equation about 5%.

The high intercorrelation of independent variables severely limits the use of multiple regression techniques in soils research. In this study the increase in R^2 by multiple regression added little to the simple regression R^2 value.

Another difficulty in using regression techniques was that occasionally the residuals were not randomly distributed. Draper and Smith (1966) stated that the errors must be independent, have a zero mean and constant variance, and follow a normal distribution. Variables such as total bases, exchangeable calcium and magnesium, when used as independent variables, tended to have residuals grouped toward the lower dependent variable values. This grouping of residuals reflected the variable sample distributions. (See Figs. 29 to 34). According to Draper and Smith, the variance was not constant and indicated a need for weighted least squares analysis. In most of the regression analyses given in this section, the residuals did not show trends and had random distribution of residuals. A few regression equations showed some weak trends in residuals, but the R^2 values were very high and the regression coefficients were statistically significant.

<u>Accuracy of Regression Equations</u> To test the accuracy of the regression equations that had been developed, a control group of soils was deleted from the analyses. In testing the regression equations it was assumed that the two variables, organic carbon and total bases, had been determined.

With use of the relationship given in Fig. 42, nitrogen was predicted. The predicted values of nitrogen corresponded closely with the actual values of nitrogen (Table XIII). There were some deviations at the higher nitrogen values.

With use of the equation (2) given in Table XIII, values for predicted nitrogen and the actual values for total bases were used to predict cation exchange capacity.

TABLE XIII. PREDICTION OF SELECTED PROPERTIES FROM A CONTROL GROUP OF SOILS

Soil	Horizon	Obs. N	$\hat{N}$	Obs. CEC	$\widehat{CEC}$	Obs. Ca	$\hat{Ca}$	Obs. Mg	$\widehat{Mg}$	Obs. Base Sat.	$\widehat{\text{Base}}$ Sat.
1	1	0.55	0.88	28.3	38.1	1.4	2.4	2.3	1.9	15	11
1	2	0.28	0.39	17.5	22.4	0.2	0.3	0.8	1.1	7	5
2	1	0.23	0.23	21.3	21.3	7.3	9.3	6.2	4.2	65	65
2	2	0.11	0.08	19.9	16.6	8.1	9.2	5.3	4.2	68	82
3	1	0.69	0.64	31.2	34.0	8.2	10.3	6.2	4.6	49	45
3	2	0.21	0.20	16.2	17.4	2.7	2.2	0.9	1.8	24	22
4	1	1.66	1.41	56.1	66.5	36.4	33.3	9.5	12.5	84	71
4	2	0.75	0.38	28.7	25.6	9.7	9.0	2.5	4.1	47	52
5	1	0.95	0.75	48.8	42.3	25.1	22.5	6.9	8.8	62	76
5	2	0.45	0.33	33.5	26.3	14.6	14.4	5.8	6.0	63	80
5	3	0.11	0.08	25.0	17.1	10.2	10.3	4.3	4.6	61	89
6	1	1.71	1.40	76.6	73.9	63.3	52.4	10.0	19.1	97	100
7	1	1.75	1.46	64.4	66.9	34.4	31.7	10.2	11.9	67	65
7	2	0.66	0.41	27.0	24.9	4.7	4.9	2.8	2.7	28	30

(1) Nitrogen = 0.01 + 0.08 (Organic Carbon)

(2) Cation Exchange Capacity = 10.28 + 0.29 (Total Bases) + 30.22 ($\widehat{\text{Nitrogen}}$)

(3) Exchangeable Calcium = -0.64 + 0.71 (Total Bases)

(4) Exchangeable Magnesium = 0.20 + 0.94 (Total Bases) - 0.97 ($\widehat{\text{Exchangeable Calcium}}$)

(5) Percent Base Saturation $= \left(\frac{\text{Total Bases}}{\text{CEC}}\right) \times 100$

This type of prediction is called a "second generation" prediction. Although there were a few high residuals, the overall prediction of cation exchange capacity was good and was within reasonable limits of accuracy. In using actual nitrogen values, some of the residuals were actually higher than those derived from using predicted values.

Use of the relationship given in Table XIII enabled prediction of calcium from total bases. The results were excellent with only one large residual (Soil 6).

Exchangeable magnesium was predicted with use of predicted calcium values and actual total base values. Good results were observed for all except for soil 6.

When the actual calcium values were used, the residuals were much smaller than those derived from predicted calcium values. Residuals derived from using predicted calcium remained within an acceptable range.

The reason for using predicted variables to predict other variables was that relationships derived by regression simulated the "true" relationships between soil variables. Predictions from the "first and second generation" were, therefore, accurate.

The final test was to predict base saturation. It was an extremely sensitive value because with low cation exchange capacities, small changes in total bases produced wide variations in base saturation. When a good regression equation for predicting base saturation could not be produced, it became necessary to predict indirectly by calculating the ratio of total bases to cation exchange capacity and multiplying this ratio by 100. Because these calculations involved use of predicted cation exchange capacity values which resulted from using predicted nitrogen, this base saturation prediction was a "third generation" prediction. In third generation predictions, large but expected discrepancies from the actual values occurred. These results and the overall correspondence between actual base saturation and predicted base saturation were good.

The above tests illustrate that the regression equations developed are in general accurate over a wide range of soil conditions. In reconnaisance soil surveys, particularly in the high islands of the Pacific, a few soil samples can be analyzed for numerous properties to develop regression equations. These regression equations can be used to reduce the number of analyses needed in the future to reduce data redundancies.

Trend Surface Analysis

Krumbein (1965, 1969) defined trend surface analysis as "a procedure for separating the relatively large-scale systematic changes in mapped data from essentially non-systematic small-scale variations due to local effects" (1965). The geological sciences have used this procedure extensively. Allen and Krumbein (1962) used trend surface analysis to determine interlocking source areas feeding detritus into the Top Ashdown Pebble Bed at Wealden in southeastern England.

Harbough (1964) used trend surface procedures in oil exploration. He applied four-variable trend hypersurfaces from which optimum combinations of geologic variables indicated possible oil reserves.

The purpose of trend surface analysis is to elucidate systematic changes in variables due to some dominant regional factor. One can then simulate these changes by fitting mathematical surfaces to data points distributed on a two-dimensional plane. The axes of the plane usually represent North-South and East-West directions on the earth's surface. A contoured map of the best fitting mathematical surface shows the areal variations in properties.

Areas of local variation can be isolated by producing contour maps of the residuals. Krumbein (1962) stated that careful examination of local variation, and of patterns displayed by it, should illuminate small scale processes which probably occurred simultaneously with the more systematic large scale influences. Local variations add "statistical noise" to the residuals (difference between data points and points derived from the mathematical surface) in areas where local variations show maximum effect.

Soil scientists have made little use of trend surface analysis. Karmeli and Kinsly (1968) selected six sections of a surveyed area and fitted linear and quadratic polynomials to percent clay in the B horizons and to mean slopes. They concluded that trend surface analysis is an objective means for investigating preliminary hypotheses used in soil surveying. The mathematical surfaces show the general direction and intensity of variation of soil variables. They also noted that deviation maps are useful in revealing local phenomena.

Walker et al. (1968) used trend surface analysis to describe changes in soil variables in small drainage catenas in Iowa. They found that the trend surfaces generally had high R^2 values and that the standard error was consistantly low. Their best fitting surface was for elevation while the poorest surface was for pH. The polynomial equations were useful in predicting minimum and maximum values for soil variables and were also useful for correlating changes in soil properties of soils in small landscape segments vary systematically, Walker et al. justified the application of trend surface equations.

Theory

The two most practical methods employed to derive the best fitting polynomial surfaces to an array of data points concern (1) orthogonal polynomial coefficients and (2) multiple regression. In the first method, orthogonal polynomials for soil profiles collected according to a grid system provide the basis for calculating the reduction in total sum of squares associated with each polynomial model. This method is rapid and easy to use. The only difficulty is that soils collected during a soil survey are irregularly spaced, thus restricting the use of orthogonal coefficients to a very small survey area.

Mandelbaum (1963) presented procedures for calculating nonorthogonal polynomials, but this method is more laborious than the procedure of calculating a multiple regression equation for each surface separately from linear to quadratic to the cubic polynomial. The difference in explained variance by addition of components used in the next higher order surface (reduction of the residual sum of squares) is the contribution of that surface. Models for linear, quadratic, and cubic polynomials are in Table XIV. From examination of this table it is evident that an increase in R^2 for any one particular variable resulted from the addition of the component associated in the next higher order

TABLE XIV. POLYNOMIAL MODELS USED IN TREND SURFACE ANALYSIS

Models	Components		
	Linear	Quadratic	Cubic
Linear	$y = b_0 + b_1U + b_2V$		
Quadratic	$y = b_0 + b_1U + b_2V$	$+ b_3U^2 + b_4UV + b_5V^2$	
Cubic	$y = b_0 + b_1U + b_2V$	$+ b_3U^2 + b_4UV + b_5V^2$	$+ b_6U^3 + b_7U^2V + b_8V^2U + b_9V^3$

model.

The general form of the linear equation is: $y = b_0 + b_1U + b_2V + e$, where y is defined as the value of a particular soil property at U (North-South) and V (East-West) map coordinates, and where e is the residual. The map coordinates, U and V, may assume any unit of measure, and the location of the map zero coordinate may be arbitrary. The regression coefficients are solved by the general least squares procedure (Draper and Smith, 1966).

The solution to the linear equation may be expressed in matrix form by: $(X^TX)^{-1}\ (X^TY) = B$ The X matrix is defined as:

$$\begin{bmatrix} 1 & U_1 & V_1 \\ 1 & U_2 & V_2 \\ 1 & U_3 & V_3 \\ \hline 1 & U_n & V_n \end{bmatrix}$$

And the Y matrix as:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \hline y_n \end{bmatrix}$$

The matrix (X^TX) has as its components the sums, sum of squares, and cross products of the coordinates:

$$\begin{bmatrix} N & U_2 & V \\ U & U & UV_2 \\ V & UV & V \end{bmatrix}$$

The matrix (X^TY) has as its components the sum of Y and the cross products of Y and the coordinates:

$$\begin{bmatrix} Y \\ UY \\ VY \end{bmatrix}$$

When calculating the inverse matrix of the (X^TX) matrix, one must examine the inverse matrix for symmetry. The data points occasionally tend to be clustered in specific areas on a map, and the $(X^TX)^{-1}$ matrix becomes asymmetric due to computational errors resulting from inversion of a near singular matrix. If this condition occurs, the procedures outlined by Mandelbaum (1963) can be used to develop reliable trend surface equations. In this study all the $(X^TX)^{-1}$ matrices were symmetrical.

Multiplication of the inverse of (X^TX) by (X^TY) results in the B matrix containing the b coefficients. The calculation for total variability of y is: $y^2 = \Sigma Y^2 - \frac{(\Sigma Y)^2}{n}$, the corrected sum of squares. The proportion of variance of y explained by the model is the sum of squares of the residuals divided by the corrected sum of squares of y.

Equations for higher order surfaces are developed by expanding the original data matrix, X, to include the additional components contained in the next higher degree polynomial model. The b coefficients are obtained by following the above procedures. A computer program for calculating coefficients for linear, quadratic, and cubic polynomial models is given in Appendix II.

In most circumstances it was unnecessary to proceed to surfaces higher than cubic. The number of coefficients increased greatly and with limited data the degrees of freedom became insufficient for testing the significance of contributions obtained by adding these higher order surfaces.

Results and Discussions

Because only a few samples were collected on Savai'i trend surface analysis was applied only to Upolu. Forty-one profiles were selected for trend surface analysis which resulted in a sample density of one soil profile per 10.5 square miles. Locations for these profiles are given in Fig. 49. The base map was scaled to 1:100,000 with the units for map coordinates in inches. The arbitrary zero point was located at 13°56' 08" S latitude and 172°05' 23" W longitude.

Trend Surfaces Affected by Rainfall A technique used to study genesis of soils in many tropical areas is to sample sequences of soils beginning at sea level and continuing into high rainfall areas in the mountains. The factor that usually has the greatest influence on soil formation is climate (more specifically, rainfall). In Western Samoa the same situation exists. As mentioned under the description of the study area (p.14), the wind flows parallel to

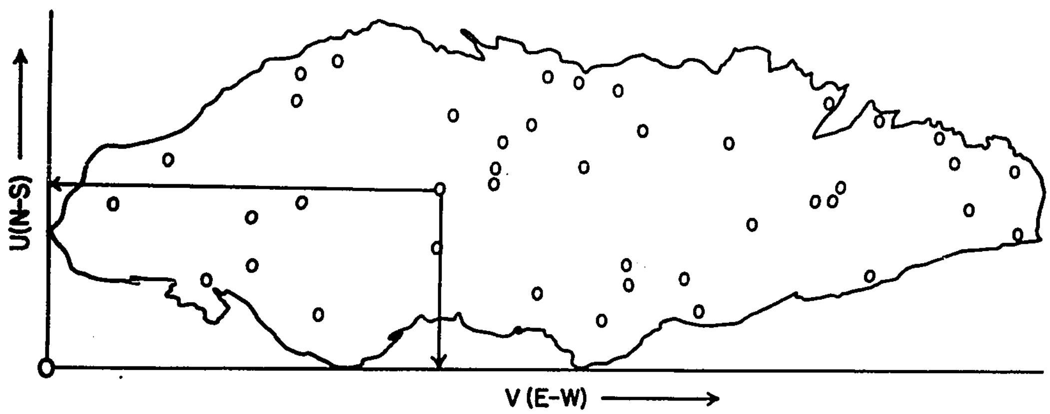


FIGURE 49. LOCATIONS OF THE SURFACE HORIZON SAMPLES USED IN TREND SURFACE ANALYSIS

the central ridge and produces a concentric weather pattern around the islands. Changes in the properties of the soils existing under these climatic zones should reflect changes in climate. Polynomial surfaces can be used to describe this two dimensional variation of soil properties in terms of map coordinates.

Results from the previous section indicated that rainfall influenced base saturation, irrespective of age. Fig. 50 shows a contoured surface of the best fitting cubic polynomial equation for base saturation in surface horizons. The correspondence between this surface and the rainfall map given in Fig. 3 was good. The R^2 value for this surface was high at 0.67. It was notable that the rain-shadow on Upolu was detected.

Another variable affected by rainfall was total exchangeable bases. The contoured cubic polynomial surface is in Fig. 51. The R^2 value (0.48) for this surface was lower than that for base saturation. The reason is that although rainfall has a great influence on total bases, cation exchange capacity which is influenced by organic matter which is in turn influenced by age of parent material, correlated with total bases. It appeared that age of parent material adds local variation or "statistical noise" to this analysis.

The exchangeable bases calcium and magnesium correlated highly with total bases. Exchangeable calcium, which had the highest correlation (0.975), had an identical cubic polynomial surface (Fig. 52) to that of total bases. Although the values of the contour lines are different, the position of the contour lines were identical. This close relationship is important because it shows that if two variables correlate very highly, the trend surface of one variable can be generated by predicting this trend surface from other variables through the use of simple regression. This technique can be used to reduce the number of analyses and computation time.

The contour lines for exchangeable magnesium (Fig. 53) deviated slightly from those of total bases and exchangeable

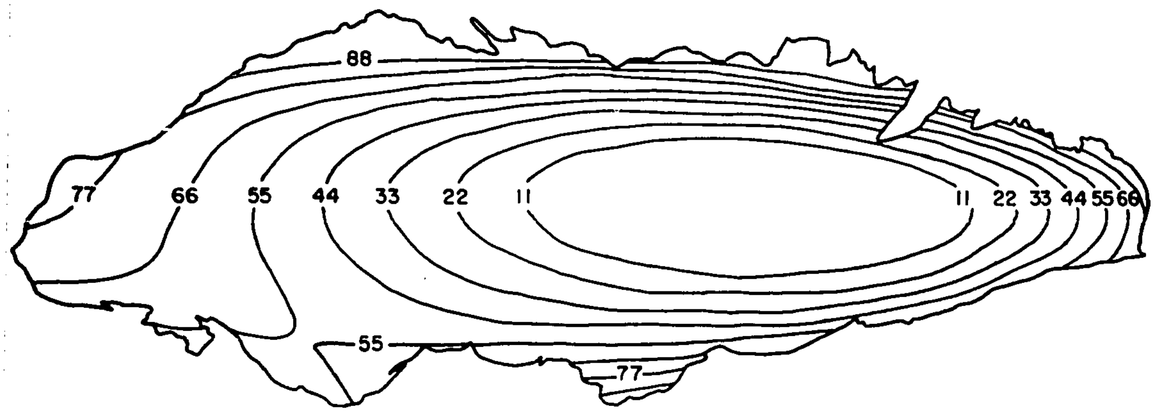


FIGURE 50. CONTOURED CUBIC POLYNOMIAL SURFACE FOR PERCENT BASE SATURATION(R^2 = 0.65)

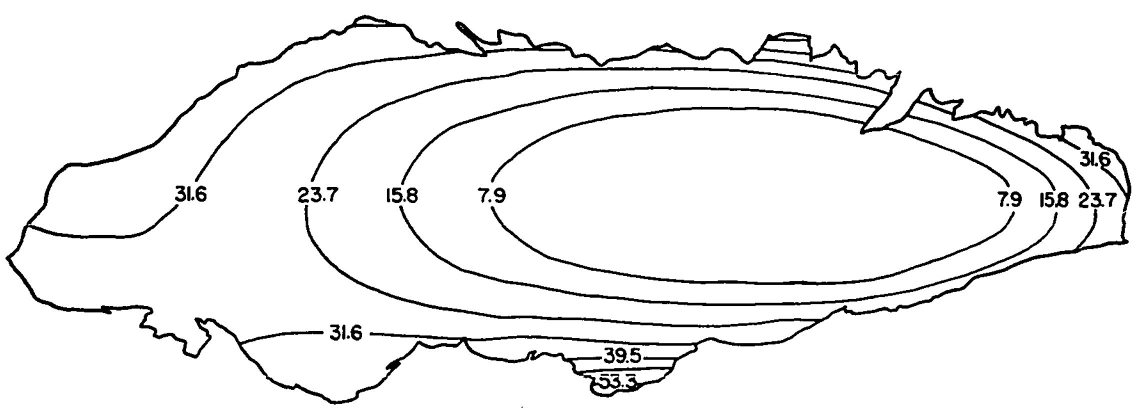


FIGURE 51. CONTOURED CUBIC POLYNOMIAL SURFACE FOR TOTAL BASES (meq/100g) (R^2 = 0.48)

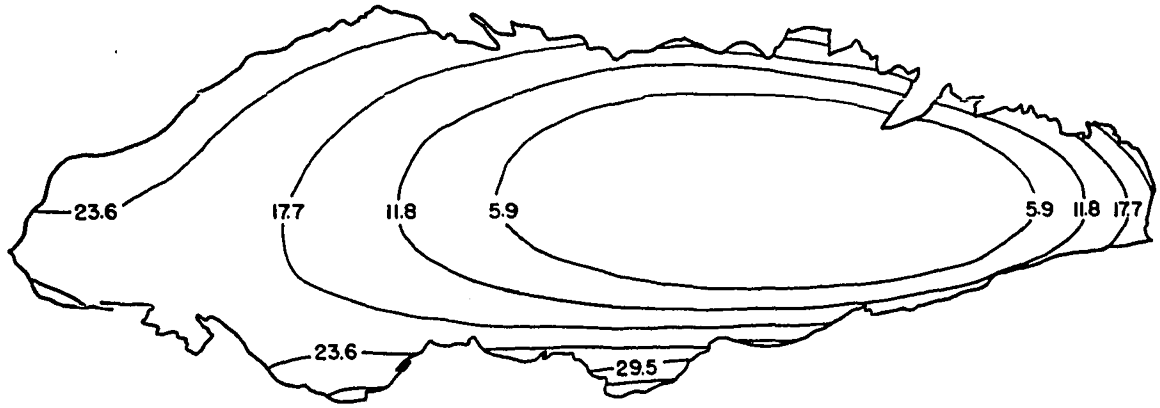


FIGURE 52. CONTOURED CUBIC POLYNOMIAL SURFACE FOR EXCHANGEABLE CALCIUM (meq/100g) $R^2 = 0.46$)

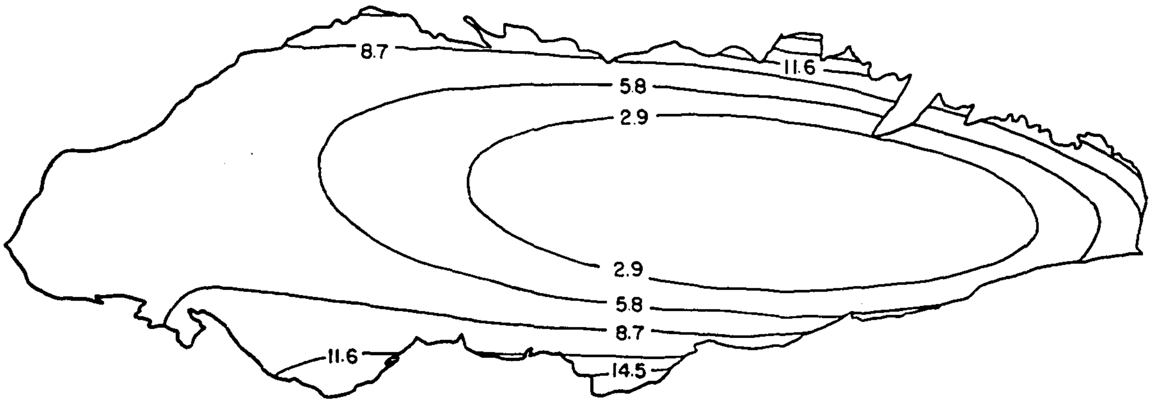


FIGURE 53. CONTOURED CUBIC POLYNOMIAL SURFACE FOR EXCHANGEABLE MAGNESIUM (meq/100g) ($R^2 = 0.51$)

calcium. The difference in R^2 was nonsignificant, a possible result of measurement error. When exchangeable calcium and total bases were the independent variables ($R^2 = 0.97$), multiple regression enabled generation of the surface for exchangeable magnesium.

<u>Trend surfaces Affected by Age of Parent Rock</u> In the section on analysis of Western Samoa soils (p.52) it was noted that age of parent material had a pronounced influence upon the organic matter content of soils. This observation was supported by the cubic trend surface for organic carbon given in Fig. 54.

Reference to the geologic map of Upolu (Fig. I) shows that areas on the geologic map that contained young volcanics were associated with the higher amounts of organic matter on the trend surfaces. The trend surface areas also indicated low organic matter corresponding to areas on the geologic map that had the intermediate to oldest volcanics. An exception occurred on Western Upolu where the soils occurred under low rainfall (90-100" MAR) and high temperatures (78°F). Trends caused by parent materials were weaker than those caused by rainfall because parent material did not exist in a systematic pattern. Contoured maps of a few residual surfaces indicated that the residuals showed more of a parent material "pattern" than a climatic pattern.

Since percent total nitrogen correlated highly with percent organic carbon, the trend surfaces were almost identical (Fig. 55). Slight shifts in contour lines between the two surfaces were caused by the choice of contour interval. Because cation exchange capacity correlated with both percent organic carbon and percent total nitrogen, the trend surface for cation exchange capacity was similar to those variables. The eastern end of the cation trend surface had residuals that indicated that rainfall was exerting a significant effect (Fig. 56).

The last trend surface, exchangeable potassium (Fig.57), appeared to have been influenced more by rainfall than by organic matter, Unfortunately, the trend was weak and was nonsignificant.

Trend surfaces are useful in testing hypotheses about soil formation in areas where several factors exert significant influences. They are also useful in making predictive soil maps, providing that the R^2 is high (usually 0.80 or greater).

<u>Trend surfaces for Genetic Factors</u> Orographically induced climatic systems commonly show systematic patterns, which can be simulated very accurately by trend surface analysis. The rainfall (MAR) and temperature (MAT) maps presented by Wright (1959) were enlarged to a scale of 1:100,000. From these enlarged maps 200 points were obtained by using the same arbitrary zero point and units of measure as used for

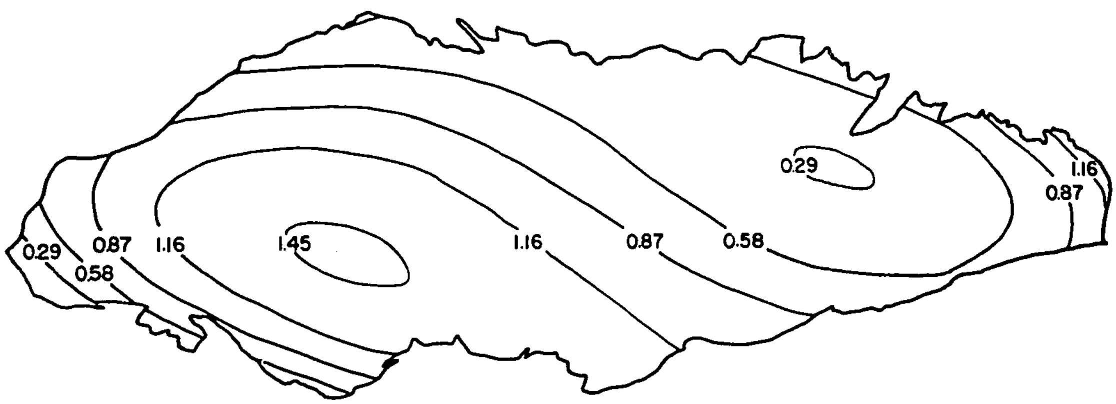


FIGURE 54. CONTOURED CUBIC POLYNOMIAL SURFACE FOR PERCENT ORGANIC CARBON (R^2 = 0.34)

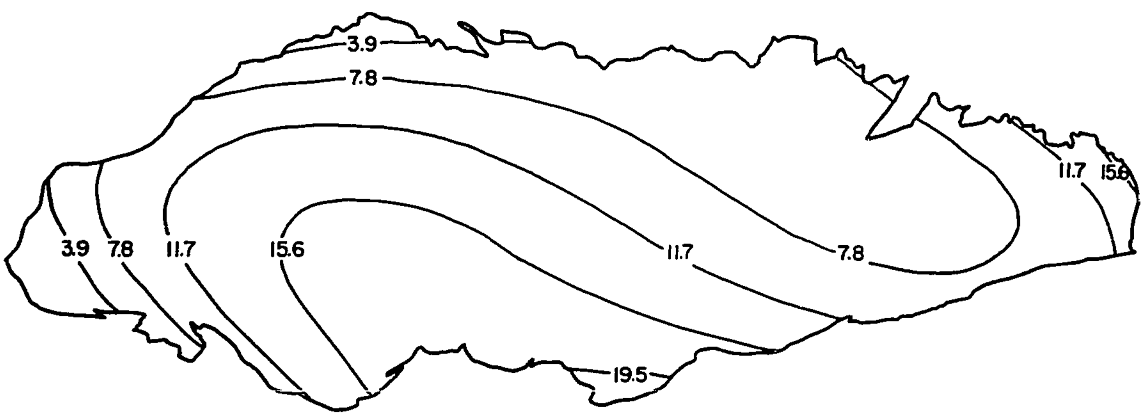


FIGURE 55. CONTOURED CUBIC POLYNOMIAL SURFACE FOR PERCENT TOTAL NITROGEN (R^2 = 0.38)

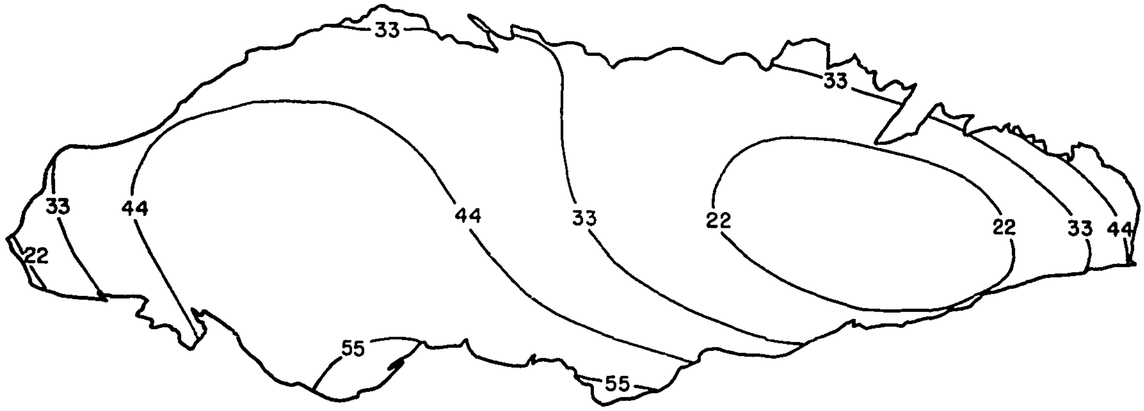


FIGURE 56. CONTOURED POLYNOMIAL SURFACE FOR CATION EXCHANGE CAPACITY (meq/100g) (R^2 = 0.37)

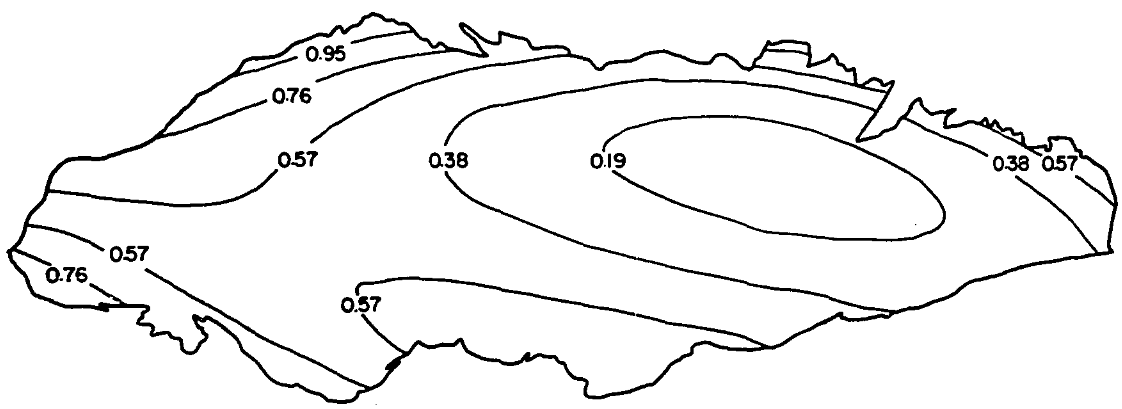


FIGURE 57. CONTOURED POLYNOMIAL SURFACE FOR EXCHANGEABLE POTASSIUM (meq/100g) (R^2 = 0.33)

soil properties. Linear, quadratic, and cubic polynomial surfaces were fitted to the points. Contours of the cubic polynomial surfaces are given in Figs. 58 and 59.

The R^2 values were very high at 0.93 and 0.85 for rainfall and temperature, respectively. These surfaces are extremely useful in prediction. If information for other climatic variables were available, such as rainfall during dry and wet seasons, and potential evaporation, accurate surfaces could be fitted to this data. These variables would be very useful in predicting areas that are susceptible to drought. In areas lacking rainfall and temperature maps, predicted maps could be made by fitting polynomial surfaces to the available data.

Trend surfaces also simulated topographic maps. One difficulty was that some areas of Upolu had steeper terrain than other areas. A surface fitted to the entire island had a low R^2 value. Division of Upolu into sections that had relatively uniform terrain solved this difficulty. Polynomial surfaces easily fitted each section. The only requirement in developing surfaces for each section was that common points on the borders of each two sections be used. This process insures that when the sections are joined into a mosaic, the surfaces are matched within reasonable limits. A mosaic of polynomial surfaces can thus represent an extensive area containing large variations in landform.

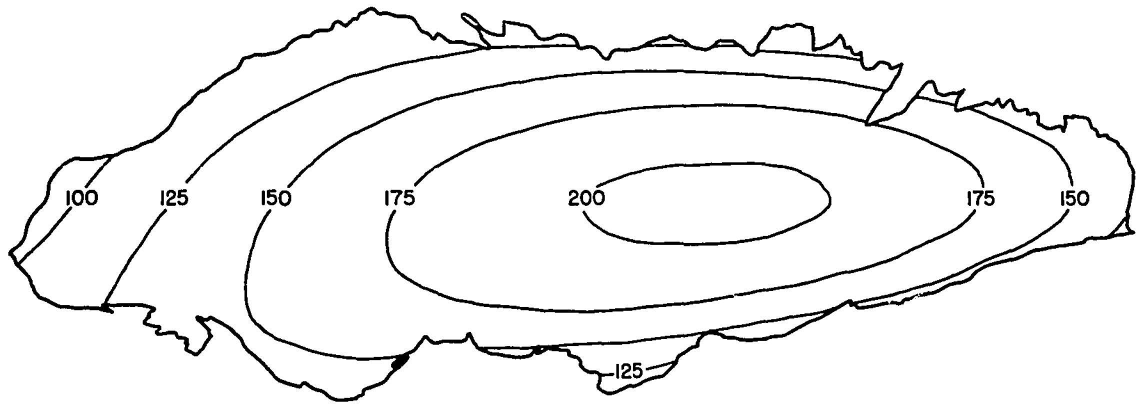


FIGURE 58. CONTOURED POLYNOMIAL SURFACE FOR MEAN ANNUAL RAINFALL (R^2 = 0.92)

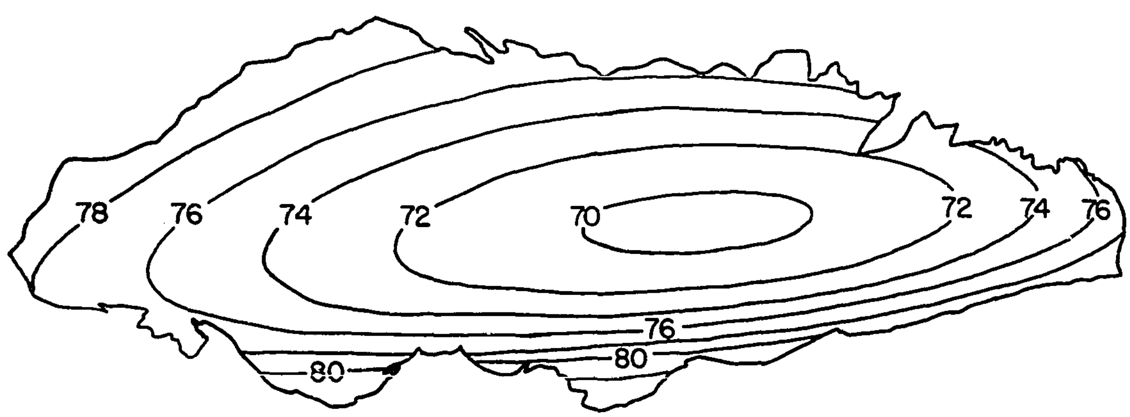


FIGURE 59. CONTOURED POLYNOMIAL SURFACE FOR MEAN ANNUAL TEMPERATURE (R^2 = 0.85)

Upolu was divided into seven sections. A polynomial surface representing elevation was fitted to data obtained from topographic maps. Five quadratic and two cubic polynomial surfaces, the R^2 values ranging from 0.85 to 0.92, were used to represent elevation. The points common to each section of the mosaic were matched within 40 feet, a good agreement because data points were obtained from 250' contour intervals.

Information in addition to elevation can be derived from these elevation surfaces. Since the maximum slope was in the N-S direction on Upolu, except on the western and eastern ends of the island, the partial derivative of the equation for the surface with respect to U $(\frac{\partial U}{\partial E})$ can be used to derive the average slope. On the eastern and western ends of Upolu, the maximum directional deviation from each point was used.

In applying this partial differentiation to the elevation surfaces derived on Upolu, the partial derivitive tended to give an underestimate of the actual slope. The reason is that the U was approximately 1.5 miles. If a smaller unit of measure were used, such as 1,000 feet or less, a more accurate prediction of slope could be obtained.

<u>Testing Significance of Trend Surfaces</u> From inspection of Table XIV, it is apparent that a sequential F test may be used to test the additional contribution of each surface.

The F test, in the strict statistical sense, must be used with caution. In fitting surfaces to data points, it is possible that the surface may be better fitted to some areas than to other areas. Bias can be introduced into the residuals by this lack of uniformity of fitting a surface. If there is bias introduced in the residuals, the assumption for the F test, normal distribution of residuals, could be violated. The interpretation of the F test then could be questionable.

To avoid this situation, the F test is used only as an index (Krumbein and Graybill, 1965). Percentiles of the F distribution are used to derive confidence levels for the F values such as those given in Table XV. For example, the 90^+ confidence level is interpreted as one time out of ten, the F value would occur when the null hypothesis, that the trend surface tested shows no existing trend, would be true.

The testing of significance is somewhat arbitrary, and the minimum acceptable confidence level is left to the discretion of the researcher. In this study the minimum acceptable confidence level was 90^+. Two cubic surfaces, percent organic carbon and exchangeable potassium, had confidence levels below 90^+ showing no significant trends.

<u>Map Prediction</u> In working with trend surface analysis, particularly in areas similar to Upolu, difficulty arises

in fitting surfaces to subsoil variables. The reason is that the effect of climate diminishes with depth, and the resulting trends become weaker with depth. More research should be made into mathematically describing vertical distributions of properties in a soil profile. The ideal method would involve relating surface soil properties to subsoil properties so that subsoil polynomial surfaces could be derived from the surface soil polynomial surface. Nevertheless, knowledge of the areal distribution of surface soil properties is extremely useful to agriculture.

To obtain the maximum usefulness of trend surface analysis, several surfaces could be combined to form a single surface which would show optimum areas for a particular purpose. Figure 60 is a surface that resulted from screening polynomial surfaces for cation exchange capacity, base saturation, and temperature. These properties had limits chosen to correspond to various criteria in the U. S. Comprehensive Soil Classification System for various subgroups for Entropepts, Dystropepts, and Humitropepts. Since these criteria apply to the entire soil profile, the combined surface is a special classification of surface horizon. The combined surface was an accurate representation of what actually existed.

Trend surfaces can be used to construct any special purpose map in a short time. For example, it was hypothesized that a special map was needed to delineate areas in

TABLE XV. ANALYSIS OF VARIANCE TABLES FOR SELECTED TREND SURFACES

Base Saturation

Source of Variation	df	MS	F	% confidence	R^2
Due to Linear	2	1660.57	1.56	75^+	7.58
Residual	38	1066.30			
Due to Quadratic	3	7069.54	12.81	99.9^+	48.37
Residual	35	551.74			
Due to Cubic	4	1017.70	2.07	90^+	9.28
Residual	31	491.68			
Due to all Components	9	3177.62	6.46	99.9^+	65.23

Total Bases

Source of Variation	df	MS	F	% confidence	R^2
Due to Linear	2	544.62	1.84	82^+	8.82
Residual	38	296.18			
Due to Quadratic	3	1245.01	5.79	99.5^+	30.26
Residual	35	214.85			
Due to Cubic	4	278.21	1.35	70^+	9.02
Residual	31	206.68			
Due to All Components	9	659.68	3.19	99^+	48.10

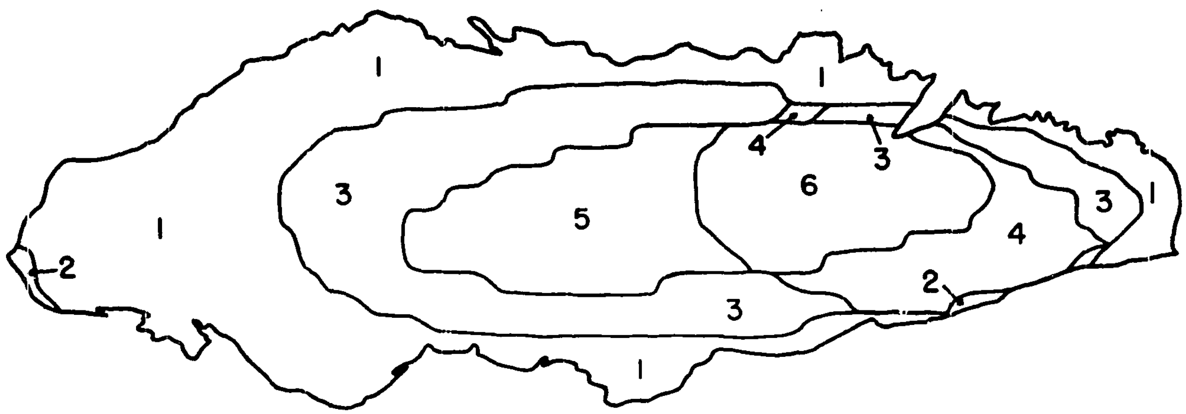
TABLE XV. (Continued) ANALYSIS OF VARIANCE TABLES FOR SELECTED TREND SURFACES

Organic Carbon

Source of Variation	df	MS	F	% Confidence	R^2
Due to Linear	2	132.11	3.46	95^+	15.40
Residual	38	38.21			
Due to Quadratic	3	7.14	0.175	10^+	1.25
Residual	35	40.88			
Due to Cubic	4	73.17	1.99	85^+	17.05
Residual	31	36.71			
Due to All Components	9	64.26	1.75	85^+	33.70

Cation Exchange Capacity

Source of Variation	df	MS	F	% Confidence	R^2
Due to Linear	2	970.90	3.93	99.9^+	17.16
Residual	38	246.90			
Due to Quadratic	3	133.94	0.52	25^+	3.54
Residual	35	256.53			
Due to Cubic	4	449.49	1.94	85^+	16.88
Due to All Components	9	440.18	1.99	90^+	36.58



LEGEND:

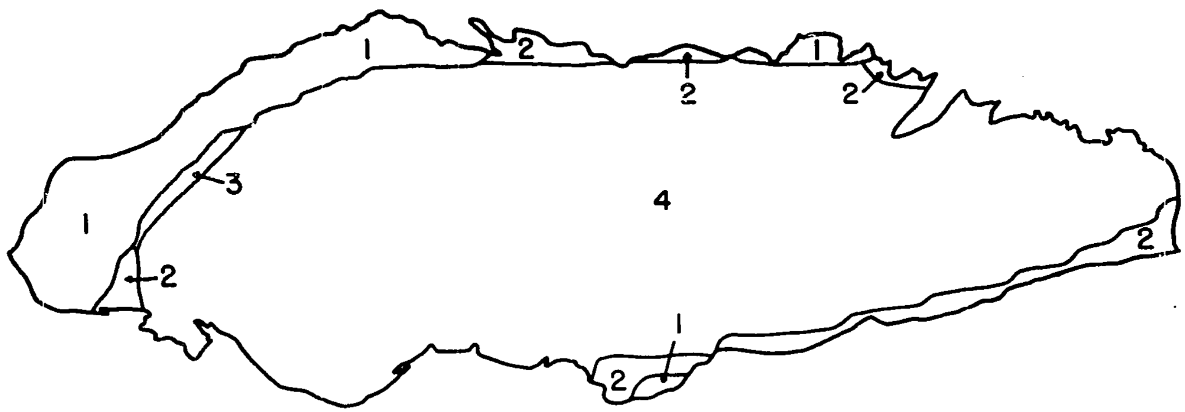
	BASE SATURATION (%)	C.E.C.(meq/100g)	TEMPERATURE (°F)
1	GT 50	GT 24	GT 72
2	GT 50	LT 24	GT 72
3	LT 50	GT 24	GT 72
4	LT 50	LT 24	GT 72
5	LT 50	GT 24	LT 72
6	LT 50	LT 24	LT 72

FIGURE 60. PREDICTED SOIL MAP FOR SURFACE HORIZONS

which the soils had greater than 50% calcium saturation and occurred in rainfall areas of less than 125" (MAR). The three surfaces were cation exchange capacity, exchangeable calcium, and rainfall. The resulting surface is given in Fig. 61. The soils are ranked from one to four depending on their limitations. These maps were predicted and merely indicated possible areas of optimum conditions.

Another use for trend surfaces is the study of two dimensional transacts. Cross sections for trend surfaces can go in any direction by varying U or V on both appropriately. Figure 62 shows cross sections of four surfaces: Base saturation, rainfall, and two surfaces for elevation. These cross sections resulted from holding V constant at 11.0 and incrementing U in units of 0.5 (0.75 miles). Base saturation, as expected, decreased with increasing rainfall and elevation. The lowest base saturation did not correspond to the highest rainfall. The reason is that at the highest elevation of this transact there was a small plateau or level area. The soils occurring on this plateau were more leached than those on the north and south slopes. The elevation curve did not show this plateau due to the exaggerated scale and the large units of U used.

The elevation curve evolved from two surfaces (north and south). The common boundary of these surfaces deviated



LEGEND:

	LIMITATIONS	Ca SATURATION	RAINFALL (MAR)
1	NONE	GT 50	LT 125
2	RAINFALL	GT 50	GT 125
3	%Ca SAT.	LT 50	LT 125
4	%Ca SAT. & RAINFALL	LT 50	GT 125

FIGURE 61. SPECIAL PURPOSE SOIL MAP

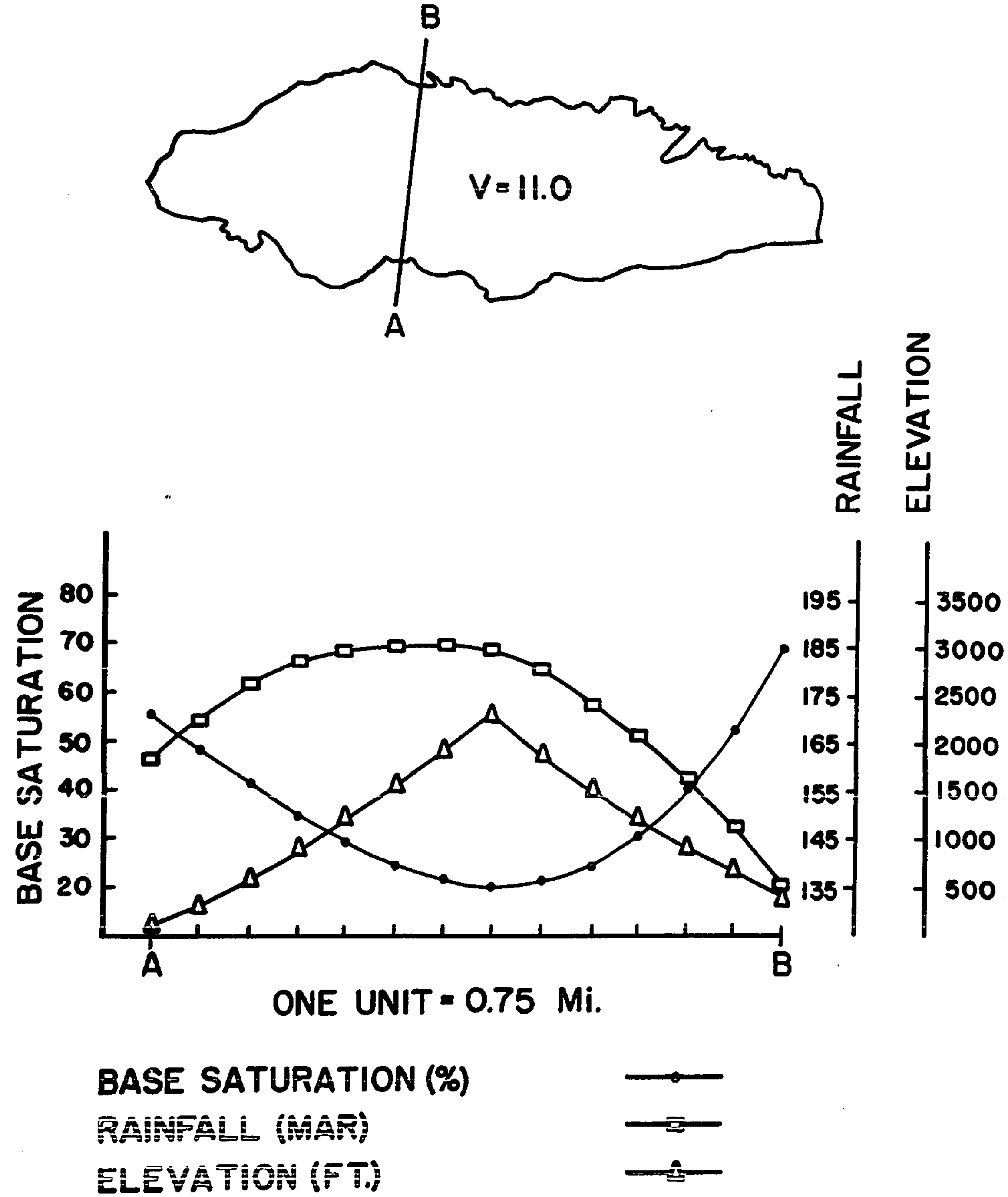


FIGURE 62. CROSS SECTIONS OF FOUR POLYNOMIAL SURFACES

only about 35 to 40 feet. Maximum rainfall occurred slightly to the leeward of the mountain crest similar to the situation on Oahu (Mink, 1960).

Nested Analysis of Variance

Introduction

Nested or hierarchial classification of samples have been used in geologic and soil research to minimize the amount of samples and laboratory determinations needed to provide estimates of regional and local variability of data. Krumbein and Slack (1956) used a modified interlocked hierarchial design to estimate regional and local variability of radioactivity of black fissle shale. Potter and Olson (1954) (Olson and Potter, 1954) used a nested classification design involving several levels of sampling to ascertain the true cross-bedding dip direction of rock formations over extensive areas in Illinois. This design was successful in separating local influences that obscured regional trends. Estimation of variance components provided weighted means for the various sampling levels.

Reed and Rigney (1947) analyzed soils from a field containing a uniform soil type and from another field containing hetrogeneous soil types. They employed a nested analysis of variance design to ascertain what level of sampling should be used in uniform and nonuniform soil areas. Their general conclusion was that refining laboratory methods was unnecessary in most cases since soils in both uniform and nonuniform areas showed considerable variability even at the lowest level of sampling. Youden and Mehlich (1937) sampled soils over an area covering several square miles to show relative efficiency of various sample spacing. Calvin and Miller (1961) presented sampling designs based on incomplete dichotomies (unequal number of samples) to determine major sources of variability in data resulting from field plots.

In this study the nested or hierarchial classification analysis of variance was used in a somewhat different manner. As suggested from examination of the U. S. Comprehensive Soil Classification System, a hierarchial design was used to derive estimates of components of variance for the various levels of classification with a minimum amounts of sampling. From these components weighted means for the different classification groups were estimated. The analysis of variance design was also used to test for relative variability to answer the question of: Do groups differ more among themselves than do the subgroups within them? A second statistical test was made to determine if units at any level were homogeneous among themselves.

The Analysis of Variance Model

The classification of 49 Western Samoa soils is in Fig. 63. It is apparent that this classification contains both unequal groups with each level and unequal samples within groups. This model is:

$$X_{ijkm} = u + \alpha_i + \beta_{ij} + \gamma_{ijk} + \partial_{ijkm}$$

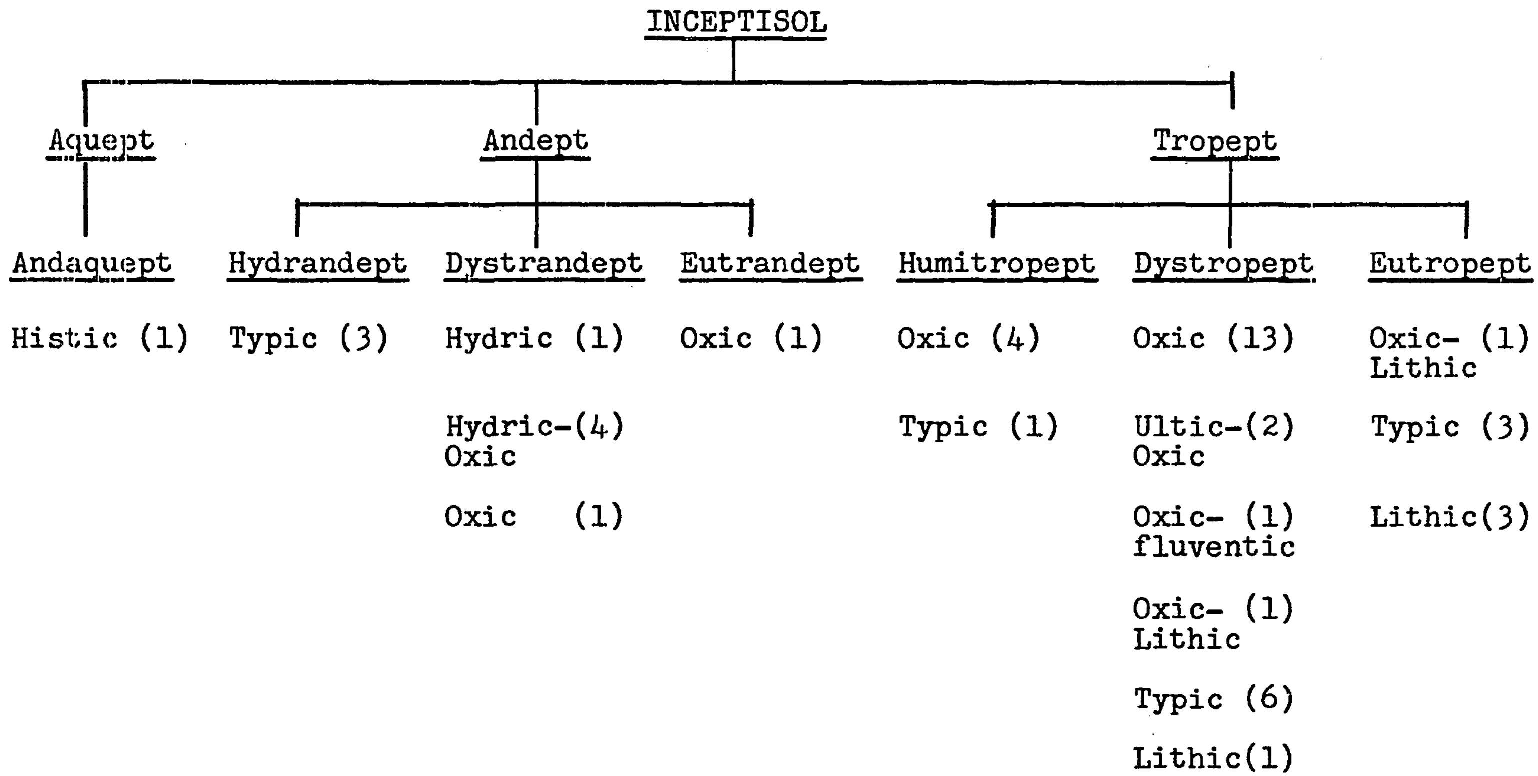


FIGURE 63. HIERARCHIAL GROUPING OF SURFACE HORIZONS FOR ANALYSIS OF VARIANCE

where X_{ijkm} = a single observation

u = the grand mean

α_i = an effect common to every sample in the i Suborder

β_{ij} = an effect common to every sample in the j^{th} Great Group of the i Suborder

γ_{ijk} = an effect common to every sample in the k^{th} Subgroup of the j^{th} Great Group of the i^{th} Suborder

δ_{ijkm} = an effect of the m^{th} sample of the k^{th} Subgroup of the j^{th} Great Group of the i^{th} Suborder

The grand mean u is constant and the parameters α_i, β_{ij}, γ_{ijk}, and δ_{ijkm} are all random variables that are independently distributed about zero means and variances of σ^2_{SO}, σ^2_{GG}, σ^2_{SG} and σ^2.

Estimation of Variance Components

Because of the unequal number of groups and samples in each level of classification, estimation of the components of variance, σ^2_{SO}, σ^2_{GG}, σ^2_{SG}, σ^2, involves calculation of special coefficients to estimate variance components from mean squares. Calvin and Miller (1961), Fryer (1966), Anderson and Bancroft (1952) and Snedecor (1957) presented procedures for calculating these coefficients. The computer program in Appendix II calculates the analysis of variance and coefficients necessary to determine variance components for designs containing ten or less levels (unequal groups and unequal samples/group).

If each group in any one level were to contain a constant number of samples, the coefficients for the variance components at that level would remain constant in the expected mean values of higher levels. The value of these coefficients would be the sample sizes which represent the number of times the components would be present. If the groups were to contain unequal sample sizes, the coefficients would represent the effective sample size. Since the sample size varies for each level, the effective sample size also varies.

The expected mean squares for the Western Samoa design are in the top portion of Table XVI. Interpreted as representing estimates of total variability at corresponding classification levels, these mean squares contain contributions from variabilities of lower levels in the nested design. The variance components represent the average variability at corresponding classification levels. The variance components for the six variables from Western Samoa soils are in Table XVII.

Examination of these variance components shows several predictable results. First, it is notable that the largest variance component for base saturation occurs at the Great Group level. The reason is that base saturation

TABLE XVI. VARIANCE COMPONENT ANALYSIS

(A) Component analysis using exact formulas

Mean Square	Estimated Components
Suborder	$\sigma^2 + 2.413\ \sigma^2_{SG} + 4.883\ \sigma^2_{GG} + 9.286\ \sigma^2_{SO}$
Great Group	$\sigma^2 + 3.028\ \sigma^2_{SG} + 5.936\ \sigma^2_{GG}$
Subgroup	$\sigma^2 + 2.629\ \sigma^2_{SG}$
Surface Horizon	σ^2

(B) Component analysis using Snedecor's Approximating Formula

Mean Square	Estimated Components
Suborder	$\sigma^2 + 2.701\ \sigma^2_{SG} + 5.585\ \sigma^2_{GG} + 9.285\ \sigma^2_{SO}$
Great Group	$\sigma^2 + 2.701\ \sigma^2_{SG} + 5.585\ \sigma^2_{GG}$
Subgroup	$\sigma^2 + 2.701\ \sigma^2_{SG}$
Surface Horizon	σ^2

TABLE XVII. VARIANCE COMPONENTS (DERIVED FROM EXACT FORMULAS)

	% Base Saturation	Exchangeable Calcium (meq/100g)	Cation Exchange Capacity (meq/100g)	Percent Organic Carbons	Percent Total Nitrogen	pH
Between Suborders (within Inceptisols)	58.47	0.00	0.00	11.02	0.0097	0.2013
Between Great Groups (within a Suborder)	555.54	74.47	176.29	5.37	0.0014	0.0432
Between Subgroups (within a Great Group)	263.66	178.92	448.75	26.60	0.0344	0.1344
Between Surface horizons (within a Subgroup)	291.33	276.84	394.97	36.79	0.0437	0.1893

is used as a criterion for separating Great Groups. Similarly, cation exchange capacity is used as a criterion for separating Subgroups, the largest variance component for cation exchange capacity consequently occurring at the Subgroup level. That there is no variability between Suborders for exchangeable Ca and CEC is indicated by the zero variance components at the Suborder level. The remaining three variables (organic carbon, total nitrogen, and pH) were observed to vary between Suborders, but the variability between Great Groups was shown to be considerably less. Variability between groups at the Subgroup and Surface Horizon levels was increased for all variables by detailed subdivision at these levels.

Estimation of Weighted Means

Olson and Potter (1964) presented a method to derive weighted means of groups in a nested classification design. The basis for their method is that the information provided about the true mean expressed as the reciprocal of the variance of the mean of a group containing many subgroups is proportional to the number of Subgroups.

For example, the variance component value for base saturation at the (within) Subgroup level (291.33 = S) is used to estimate the variance of the Great Group means by S/ (effective sample size for a particular Great Group). The effective sample size is calculated by a formula presented by Snedecor (1957, p. 270), resulting in the effective sample size for Dystropepts of 3.280. Information that the various Subgroups means of Dystropepts supply on the Dystropept mean is gained by dividing this value (3.28) into S and taking the reciprocal of the resulting value. This reliability or information is used as a weighting factor to multiply against corresponding Subgroup means in computing the weighted Great Group mean. This weighted mean is calculated by:

$$\bar{X}\ (\text{Great Group}) = \frac{\sum_{i=1}^{k} (X_i . w)}{\sum_{i=1}^{k} w}$$

where k = the number of Subgroups and w is the weighting factor.

When this procedure is extended to provide estimates of Suborder means, another component is added, the Great Group component of variance. The new sample size is based on effective sample size of the Great Group. The information or reliability of the Great Group means as estimates of the Suborder mean is formulated as: $\frac{1}{w = S^2/(\text{Effective Sample Size} + S^2_{GG})}$. Weighted means for percent base saturation exchangeable calcium, cation exchange capacity, and organic carbon for several classification levels are given in Table XVIII. In most cases, the difference between the weighted mean and unweighted mean was small. Accurate group means are effectively produced by this weighting procedure.

TABLE XVIII. WEIGHTED MEANS

	Base Saturation	Exchangeable Calcium	Cation Exchange Capacity	Organic Carbon
Andept	29.09 (16.11)	7.71 (4.80)	56.48 (55.69)	17.06 (17.83)
Tropept	46.59 (47.27)	20.31 (19.04)	52.30 (46.91)	12.44 (11.18)
Humitropept	16.33 (13.70)	6.89 (3.87)	57.84 (41.24)	14.06 (10.08)
Dystropept	48.37 (44.35)	16.39 (15.87)	39.70 (39.99)	9.88 (9.59
Eutropept	85.73 (81.66)	40.24 (41.20)	69.50 (75.67)	15.77 (17.67)

Numbers in parentheses are unweighted means.

Tests of Hypotheses

The nested classification analysis of variance design is useful in testing for relative variability and homogeneity of individual classification levels. Relative variability refers to comparing the variatility of groups among themselves for one level to the variability of subgroups within them in the next lower level. This test involves computing an F value from the mean squares of the levels being compared. With unequal sample numbers in each group, difficulty arrises because the quantity $\frac{\sigma^2 + C_2\sigma^2_{SG} + C_3\sigma^2_{GG}}{\sigma^2 + C_1\sigma^2_{SG}}$ does not reduce to unity if $\sigma^2_{GG} = 0$ (see Table XVI). An approximate test involves using Snedecor's effective sampling size formula to provide an average value for C_2 and C_1. Snedecor (1957) stated that this test is usually sufficient in consideration of the usually large standard errors of the variance component. The components for the estimated mean squares, with Snedecor's procedure, are in Table XVI.

Values for the F test used in testing significance of the relative variability for each level of the classification of Western Samoa soils are in Table XIX. It is apparent that for all variables tested the suborder level had no significant variation between Suborders compared to the variation between Great Groups within Suborders. Likewise, the Great Group level had no significant variation between Subgroups within Great Groups. The only exception,

TABLE XIX. TESTS OF HYPOTHESES FOR RELATIVE VARIABILITY

Hypothesis	% Base Saturation	Exchange-able Calcium (meq/100g)	Cation Exchange Capacity (meq/100g)	Percent Organic Carbon	Percent Total Nitrogen	pH
(1) No significant variation between Suborders compared with variation between Great Groups in a Suborder	0.95^{ns}	0.77^{ns}	0.38^{ns}	1.54^{ns}	1.43^{ns}	2.46^{ns}
(2) No significant variation between Great Groups compared with variation between Subgroups in a Great Group	4.46^{*}	1.69^{ns}	1.78^{ns}	1.40^{ns}	1.16^{ns}	1.94^{ns}
(3) No significant variation between Subgroups compared with variation between Surface Horizons in a Subgroup	3.38^{**}	2.70^{*}	3.99^{**}	2.90^{**}	3.07^{**}	2.87^{*}

	(1)	(2)	(3)
Degrees of freedom:	2,4	4,10	10,32
$F_{0.05}$	6.94	3.48	2.14
$F_{0.01}$	10.00	5.99	2.94

ns = nonsignificant - accept hypothesis
* = significant at 0.05 level of propability
** = significant at 0.01 level of probability

as expected, for Great Groups was base saturation which was used as a criterion at the Great Group level. At the lowest level, the variation between Subgroups compared to the variation between Surface Horizons within Subgroups was significant for all variables.

The second statistical test can be used to test hypotheses about the homogeneity of individual classification levels and to answer the question: Is the variability between groups greater than the variability within these groups? To make this analysis, each classification level is tested on the basis of a single factor analysis of variance. The mean squares are recomputed according to the procedure given by Dixon and Massey (1951), essentially pooling the variance of levels below the one being tested.

Results of these tests for Western Samoa soils are in Table XX. The results indicated that classification of the soils used was good because most of the variables showed that at each level the groups had more between group variability than within group variability. The only exceptions were for exchangeable calcium and cation exchange capacity at the Suborder level. The nonsignificant F values for these variables indicated that the criteria used at the Suborder level were not effective in providing Suborders that had more variation between themselves compared with variation within themselves for these

TABLE XX. TESTS OF HYPOTHESES FOR HOMOGENEITY OF INDIVIDUAL CLASSIFICATION LEVELS

Hypothesis	% Base Saturation	Exchange-able Calcium (meq/100g)	Cation Exchange Capacity (meq/100g)	Percent Organic Carbon	Percent Total Nitrogen	pH
(1) No significant variation between Suborders compared with variation within Suborders	10.31**	3.70ns	0.76ns	6.07*	4.63*	15.15**
(2) No significant variation between Great Groups compared with variation within Great Groups	13.27**	4.35**	4.32**	4.52**	3.69*	8.40**
(3) No Significant Variation between Subgroups compared with variation within Subgroups	10.86**	5.36**	7.13**	5.46**	3.73**	7.62**

Degrees of Freedom:	(1) 1,46	(2) 4,42	(3) 9,32
$F_{0.05}$	4.05	2.59	2.19
$F_{0.01}$	7.21	3.80	3.01

ns = nonsignificant - accept hypothesis

* = significant at 0.05 level of probability

** = significant at 0.01 level of probability variables. With cation exchange capacity the highest F value occurred as expected at the Subgroup level because cation exchange capacity was a criterion at the Subgroup level.

Difficulties in Using Soils Information in AOV Designs

In the first attempt of using the nested analysis of variance design for the Western Samoa soils, an additional level (horizons within profiles) was introduced. More variation within the soil profiles than variation between the soil profiles was indicated by the results. With this large amount of variability at the lowest level, reliable estimates and tests of significance could not be made for higher levels. To use the nested analysis of variance design, therefore, only the variables of top horizons were used. Analysis of variance of the subsoil samples can also be made if desired.

SUMMARY AND CONCLUSIONS

Summary

The objective of this study was to develop statistical procedures to improve the efficiency of reconnaissance soil surveys of the high islands of the Pacific. To provide a basis for interpretating the statistical results, the author studied the nature, genesis, and classification of selected soils from Western Samoa. These soils provided sequences of soils developed in materials belonging to three different ages of volcanic and occurring under a wide range of climatic conditions. Analyses of the soil samples provided data on the dominant mineralogical characteristics, and on the chemical properties of pH, organic carbon, total nitrogen, cation exchange capacity, exchangeable bases, base saturation and free iron oxides. The U. S. Comprehensive soil Classification System provided the frame of reference for classifying all the soils sampled.

To provide enough soils for valid statistical analyses, results from soils analyzed by the New Zealand Soil Bureau were added to those soils sampled by the author. Summary statistics, means, standard deviations, coefficient of variation, skewness, and kurtosis, were calculated for the variables studied.

Parameters for the normal, lognormal, and gamma density functions representing nine variables distributions were calculated. These density functions were used to define

measures of central tendency the nine variables and were used to rank soils according to their "measure of association" with a predefined modal profile.

Regression analyses were used to develop equations to relate soil variables. Trend surface analysis was used to identify large scale systematic changes in soils from mapped data. Deviation of data points from the mathematical surface fitted to the mapped data were used to indicate sources of local variability. The trend surfaces for environmental factors were combined with soil variable trend surfaces to produce "predicted" special purpose soil maps.

Nested classification, analysis of variance design, was used to test hypotheses about relative variability of soil classification levels and to test hypotheses about the homogeneity of individual classification levels. This analysis of variance design was used to provide estimates of the variability (variance components) of each classification level and through the use of these variance components, weighted means of groups in various classification levels were calculated.

Conclusions

(1) Rainfall and age of parent rock are the two dominant factors affecting soil formation in Western Samoa. Soils occurring on the younger volcanic material are generally lower in free iron oxides, have a higher organic

carbon content, a higher cation exchange capacity and a higher base saturation than soils occurring in comparable climatic zones in older volcanics. With increasing age, the soil mineralogy changes from weakly formed mixed layer and amorphous material to gibbsite.

The effect of rainfall is evident irrespective of age of the parent rock. With increasing rainfall, the base saturation of the soil decreases, the free iron content increases, the depth of solum increases, and the gibbsite content increases.

(2) The majority of the soils in Western Samoa are Inceptisols. The largest Suborder is Tropepts and the two largest Great Groups are Dystropepts and Humitropepts. The vaguely defined criteria for Tropepts and various groups within the Tropepts in the U. S. Comprehensive Soil Classification System cause some difficulty in classifying some of the Western Samoa soils. Future research should investigate the nature of tropical Inceptisols, particularly those in the high islands of the Pacific,

(3) Distributions for many soil variables that are highly skewed can be represented by lognormal and gamma population density functions. These density functions provide better estimates of central tendency than the arithmetic mean.

(4) Simple and two variable multiple regression

equations can produce accurate predictions of soil variables over a wide range of conditions.

(5) Trend surface analysis becomes a valuable tool in elucidating soil variable areal distributions where a dominant soil forming process is operating in a systematic pattern. Trend surfaces can simulate environmental factors of rainfall (MAR), temperature (MAT) and topography very accurately. When the R^2 for trend surfaces of soil variables is high, these surfaces may be combined with the environmental factors to make predicted soil maps.

(6) Nested classification analysis of variance models may be used (a) to estimate variability of classification levels with a minimum amount of sampling, (b) to calculate weighted means for classification groups, and (c) to test hypotheses about the relative variability and the homogeneity of the various levels of classification.

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APPENDIX I

VAISALA SERIES

The Vaisala series is a member of the clayey-skeletal; mixed, isohyperthermic family of the Lithic Eutropepts.

Typifying Pedon: Vaisala stony and bouldery clay
(colors are for moist soil)
(All textures are "apparent field textures")

0 - 25 cm --Very dark brown (10YR 2/2) stony and bouldery clay; nonsticky and nonplastic.

25 cm+ --On Mulifanua lava boulders.

Type Location: Western Savai'i

Setting: Mean annual rainfall varys from 85 to 90 inches. mean annual temperature is 78°F. This soil experiences three very dry months and four to moderately dry months. Elevation ranges from sea level to 750 feet.

Drainage and Permeability: Well drained; permeability rapid.

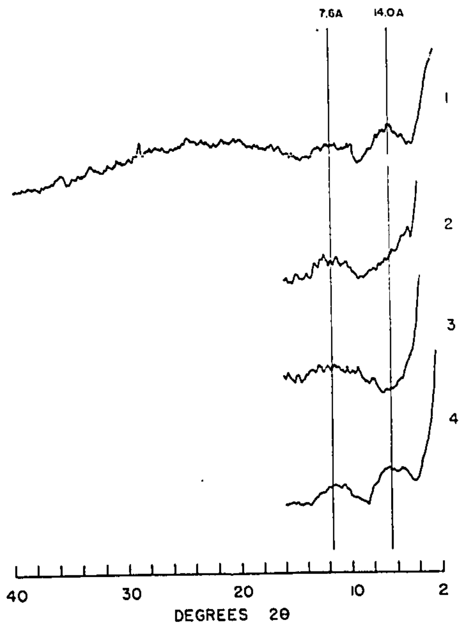

FIGURE 64. VAISALA X-RAY DIFFRACTION PATTERNS: 1) K SAT. ROOM TEMP., 2) 350°C, 3) 550°C and 4) Mg GLYCOLATED.

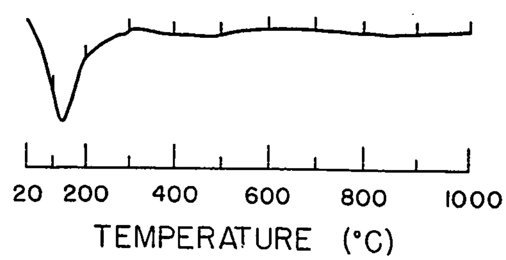

FIGURE 65. VAISALA DIFFERENTIAL THERMAL ANALYSIS

TABLE XXI. VAISALA CHEMICAL ANALYSIS

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0--25	6.0	5.6	-0.4	76.60

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0--25	0.41	0.70	47.68	9.70	76.6

Depth (cm)	%Fe_2O_3	% Organic Carbon	%Total Nitrogen	C/N
0--25	6.63	17.20	1.71	10.1

1 meq/100g

SATAUA SERIES

The Sataua series is a member of the clayey-skeletal, mixed, isohyperthermic family of the Lithic Dystropepts.

Typifying Pedon: Sataua very stony clay
(Colors are for moist soil)
(All textures are "apparent field textures")

0 - 15 cm --Black (10YR 2/1) very stony clay, nonsticky and non plastic.

15 - 30 cm --Dark gray brown (10Yr 4/2) stony clay; very friable, nonsticky and nonplastic.

Type Location: Northwest Savai'i.

Setting: Mean annual rainfall varies from 90 to 115 inches. Mean annual temperature is 78°F. This soil experiences two very dry months and three to four moderately dry months. Elevation ranges from sea level to 500 feet.

Drainage and Permeability: Well drained; permeability rapid.

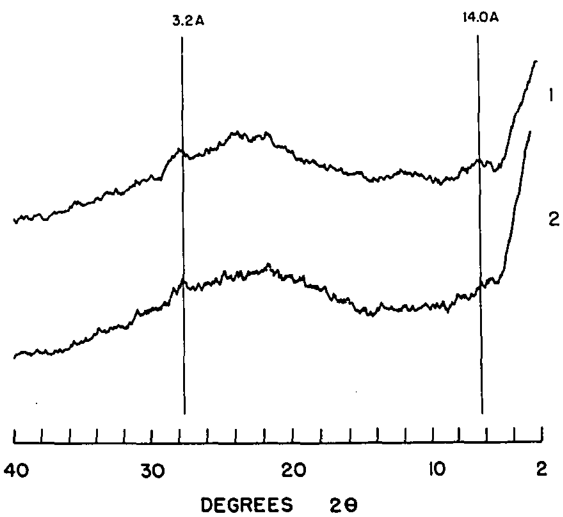

FIGURE 66. SATAUA X-RAY DIFFRACTION PATTERNS: K SATURATED, ROOM TEMP., 1) 0-15cm and 2) 15-30cm

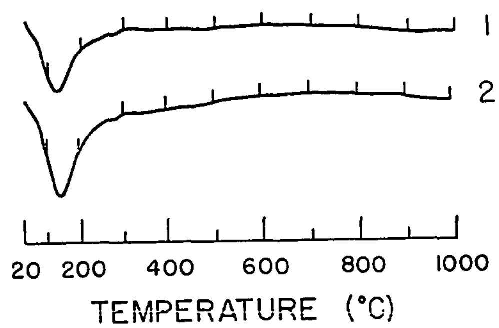

FIGURE 67. SATAUA DIFFERENTIAL THERMAL ANALYSIS 1) 0-15cm and 2) 15-30cm

TABLE XXII. VAISALA (B) CHEMICAL ANALYSIS

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-15	6.0	5.5	-0.5	56.10
15-30	5.9	5.2	-0.7	28.70

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-15	0.36	1.28	33.55	8.62	78.0
15-30	0.19	0.16	7.83	2.03	36.0

Depth (cm)	% Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-15	3.40	17.30	1.66	10.0
15-30	4.51	4.50	0.75	6.0

1 meq/100g

SALEIMOA SERIES (A)

The Saleimoa series is a member of the clayey-skeletal, mixed, isohyperthermic family of the Typic Dystropepts.

Typifying Pedon: Saleimoa very stony clay loam
(Colors are for moist soil)
(All Textures are "apparent field textures")

0 - 10 cm -- Black (5YR 2/1) very stony clay loam; strong fine to medium granular structure; soft, very friable, sticky and slightly plastic; abundant roots; many stones on the surface; smooth clear boundary.

10 - 30 cm -- Black (7.5YR 2/1) very stony silty clay loam; weak fine to medium granular and subangular blocky structure; very friable, slightly sticky, and slightly plastic; many roots; subsurface more stone than surface; gradual smooth boundary.

30 - 66+cm -- Dark brown (10YR 3/3) very stony silty clay lowm; weak coarse subangular blocky breaking to weak fine subangular blocky structure; nonsticky and slightly plastic; many roots.

Type Location: The Island of Upolu. Two and one half miles above Saleimoa village on Nono's road. [GR036707 sheet 18]

Setting: The Saleimoa soils are formed on lava belonging to the Lefaga volcanics. Elevation is 575 feet. The mean annual rainfall varies from 110 to 130 inches. The mean annual temperature is 78°F. This soil experiences one very dry month and three moderately dry months. The surface is gently rolling and very stony. (Temperature at a depth of 60 cm was 76°F on 6/26/67)

Drainage and Permeability: Well drained; permeability rapid.

Use and Vegetation: Cocoa and coconut plantations.

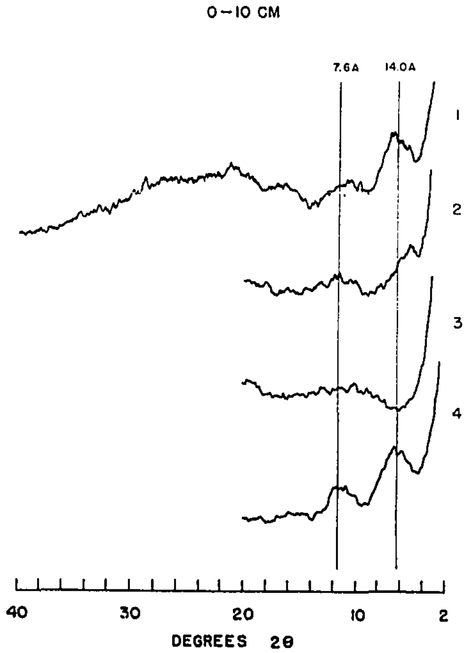

FIGURE 68. SALEIMOA (A) X-RAY DIFFRACTION PATTERNS 0-10cm, 1) K SAT. ROOM TEMP., 2) 350°C, 3) 550°C, and 4) Mg GLYCOLATED.

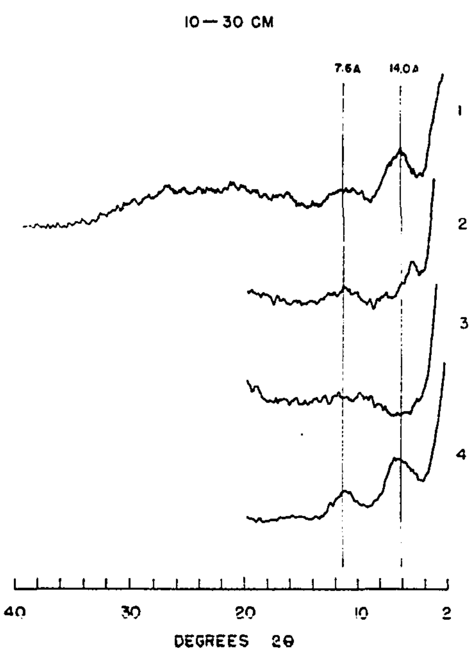

FIGURE 69. SALEIMOA(A) X-RAY DIFFRACTION PATTERNS 10-30cm 1) K SAT. ROOM TEMP., 2) 350°C, 3) 550°C and 4) Mg GLYCOLATED.

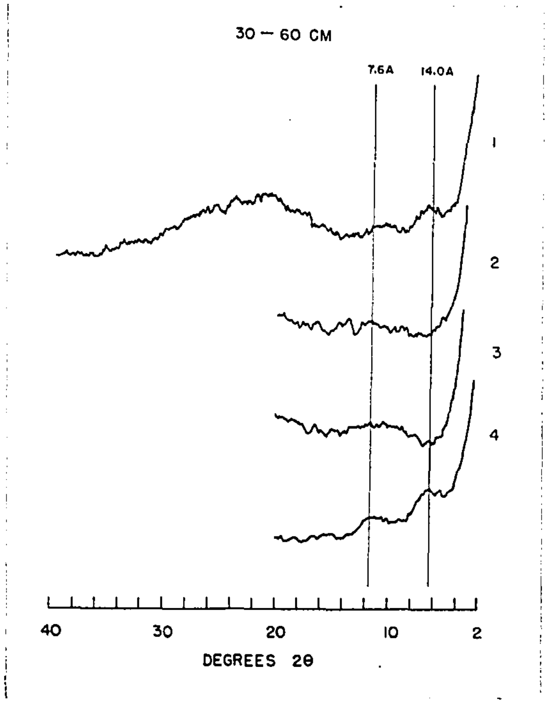

FIGURE 70. SALEIMOA (A) X-RAY DIFFRACTION PATTERNS 30-60cm, 1) K SAT. ROOM TEMP., 2) 350°C, and 4) Mg GLYCOLATED.

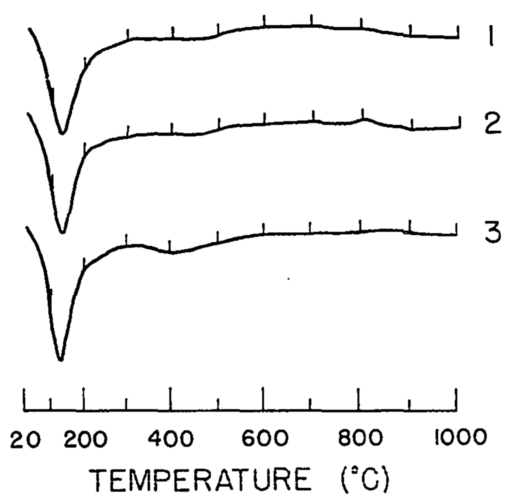

FIGURE 71. SALEIMOA (A) DIFFERENTIAL THERMAL ANALYSIS 1) 0-10cm, 2) 10-30cm, and 3) 30-60cm.

TABLE XXIII. SALEIMOA (A) CHEMICAL ANALYSIS

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-10	6.4	5.9	-0.5	73.48
10-30	6.3	5.7	-0.6	54.31
30-60	6.3	5.8	-0.5	40.41

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-10	0.26	0.50	40.12	11.32	71.0
10-30	0.28	0.24	21.82	5.42	51.0
30-60	0.09	0.05	5.41	2.20	19.0

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-10	7.01	16.98	1.41	12.0
10-30	8.77	11.15	0.98	11.0
30-60	9.16	6.51	0.55	12.0

1 meq/100g

SALEIMOA (B)

Typifying Pedon: Saleimoa gritty silty clay loam.
(Colors are for moist soil)
(All textures are "apparent field textures")

0 - 5 cm -- Very dark brown (10YR 2/2) gritty silty clay loam; weak to moderate, fine to medium, granular structure; friable, slightly sticky and slightly plastic; abundant fine roots; abrupt smooth boundary.

5 - 25 cm -- Very dark grayish brown (10YR 3/2) loam; weak and moderate medium subangular blocky structure; friable, sticky and plastic; many fine roots; gradual smooth boundary.

25 - 46 cm -- Very dark grayish brown (10YR 3/2) sandy loam; weak coarse subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; on hard basalt with irregular surface.

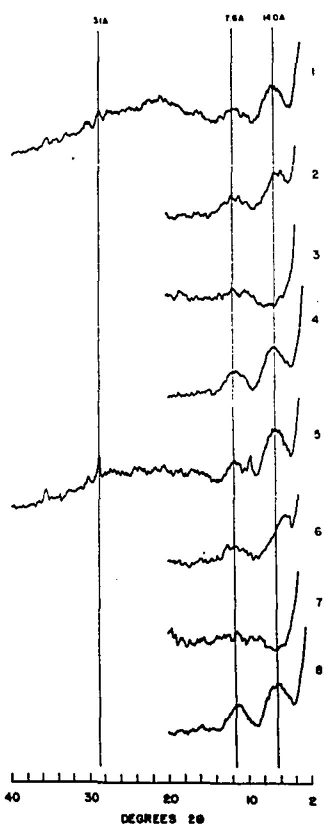

FIGURE 72. SALEIMOA (B) X-RAY DIFFRACTION PATTERNS 0-25cm 1) K SAT. ROOM TEMP., 2) 350°C, 3) 550°C, 4) Mg GLYCOLATED; 25-46cm 5) K SAT. ROOM TEMP., 6) 350°C, 7) 550°C and 8) Mg GLYCOLATED.

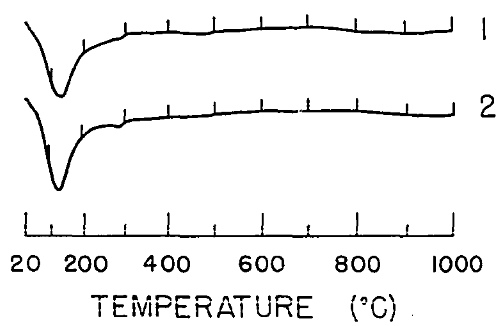

FIGURE 73. SALEIMOA (B) DIFFERENTIAL THERMAL ANALYSIS 1) 0-25cm and 2) 25-46cm.

TABLE XXIV. SALEIMOA (B) CHEMICAL ANALYSIS

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-25	6.3	5.8	-0.5	60.35
25-45	6.3	5.8	-0.5	53.26

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-25	0.41	0.23	18.44	11.45	51.0
25-45	0.32	0.06	7.10	8.43	30.0

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-25	10.01	12.07	0.86	14.0
25.45	11.30	7.37	0.65	11.0

1 meq/100g

LEFAGA SERIES

The Lefaga series is a member of the clayey-skeletal, mixed, isohyperthermic family of the Typic Dystropepts.

Typifying Pedon: Lefaga bouldery clay
(Colors are for moist soil)
(All textures are "apparent field textures")

0 - 5 cm -- Dark reddish brown (5YR 2/2) bouldery clay; firm to friable, slightly sticky, and nonplastic.

5 - 45 cm -- Dark brown (7.5YR 3/2) to dark reddish brown (5YR 3/2) bouldery clay; very friable, slightly sticky and plastic.

Type Location: Island of Upolu. At a 250 foot elevation on the cross island road traveling towards Tanumalala from Lefaga bay.

Setting: The Lefaga soils are formed on lavas belonging to the Lefaga volcanics. They generally have an elevation ranging from 200 to 750 feet. The mean annual rainfall varies from 120 to 150 inches. The mean annual temperature is 75°F. This soil experiences one moderately dry month.

Drainage and Permeability: Well drained; moderately rapid permeability.

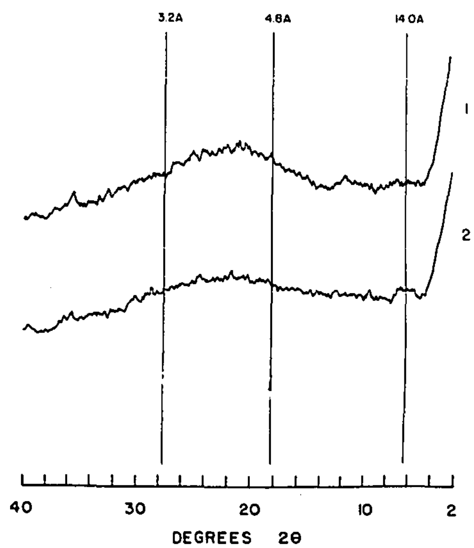

FIGURE 74. LEFAGA X-RAY DIFFRACTION PATTERNS K SATURATED, ROOM TEMP., 1) 0-5cm and 2) 5-45cm.

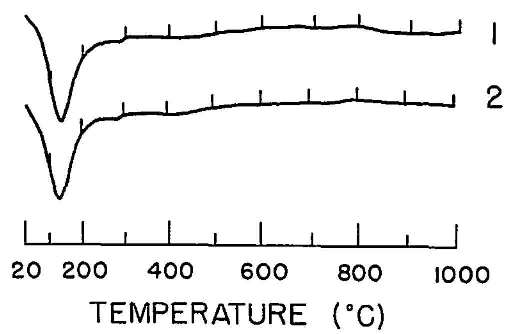

FIGURE 75. LEFAGA DIFFERENTIAL THERMAL ANALYSIS, 1) 0-5cm and 2) 5-45cm.

TABLE XXV. LEFAGA CHEMICAL ANALYSIS

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-5	5.7	5.1	-0.6	64.40
5-45	5.9	5.4	-0.5	27.00

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-5	0.37	0.55	25.37	10.57	57.00
5-45	0.18	0.12	3.68	2.80	25.00

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-5	7.20	17.90	1.75	10.0
5-45	10.65	4.90	0.66	7.0

1 meq/100g

TANUMALALA SERIES (B)

The Tanumalala series is a member to the very fine, oxidic, isothermic family of the Oxic Dystropepts.

Typifying Pedon: Tanumalala silty clay loam
(Colors are for moist soil)
(All textures are "apparent field texture")

0 - 15 cm -- Dark brown (7.5YR 3/2) silty clay loam; moderate very fine to fine subangular blocky structure; friable, nonsticky, and slightly plastic; many roots; clear smooth boundary.

15 - 30 cm -- Dark brown (7.5YR 4/2) silty clay; moderate fine to medium subangular blocky structure; very friable, slightly sticky, and slightly plastic; many roots; few stones; gradual smooth boundary.

30 - 60^{+}cm -- Dark brown (7.5YR 4/2) silty clay, weak medium subangular blocky structure; friable, sticky, and plastic; few roots; few stones.

Type Location: Island of Upolu. One mile north of Tanumalala village (Westex road) on cross island road.

Setting: The Tanumalala soils are formed on Lefaga volcanics. Mean annual rainfall varies from 130 to 175 inches. The mean annual temperature is approximately 72 to 74°F. Elevation ranges from 600 to 1800 feet. These soils do not experience any dry seasons.

<u>Drainage and Permeability</u>: Moderately well drained; moderate permeability.

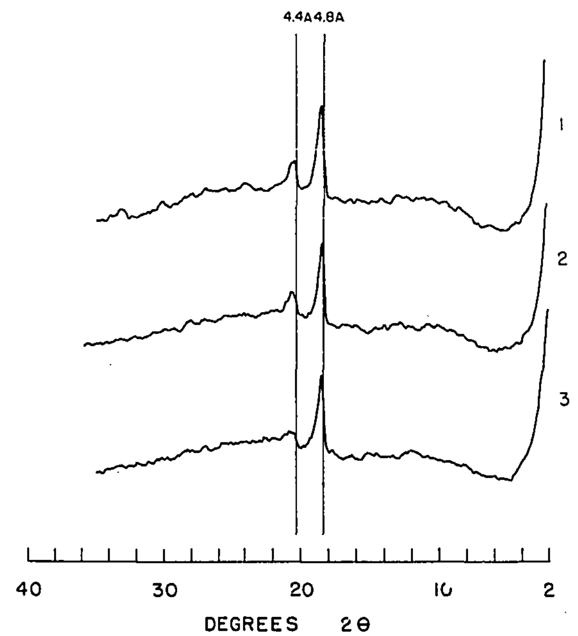

FIGURE 76. TANAMALALA (B) X-RAY DIFFRACTION PATTERNS K SATURATED, ROOM TEMP., 1) 0-15cm, 2) 15-30cm and 3) 30-60cm.

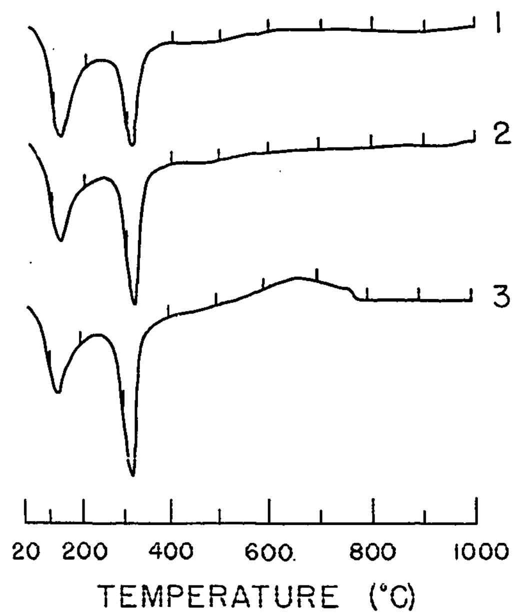

FIGURE 77. TANAMALALA (B) DIFFERENTIAL THERMAL ANALYSIS 1) 0-15cm, 2)15-30cm and 3) 30-60cm

TABLE XXVI. TANUMALALA (B) CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0--15	5.7	5.4	-0.2	35.03
15--30	5.6	5.6	0.0	31.91
30--60	5.7	6.0	0.3	26.62

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0--15	0.14	0.15	3.94	1.28	16.0
15--30	0.09	0.11	0.52	0.24	3.0
30--60	0.11	0.00	0.30	0.20	2.0

Depth (cm)	% Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0--15	18.24	5.72	0.50	11.0
15--30	20.32	3.05	0.24	12.0
30--60	20.80	0.64	0.14	5.0

1 meq/100g

TANUMALALA (A)

Typifying Pedon: Tanumalala stony clay

(Colors are for moist soil)

(All textures are "apparent field textures")

0 - 5 cm -- Dark reddish brown (5YR 3/2) stony clay; friable, nonsticky, and plastic.

15 - 50 cm -- Reddish brown (5YR 4/4) bouldery clay; very friable, slightly sticky, and plastic.

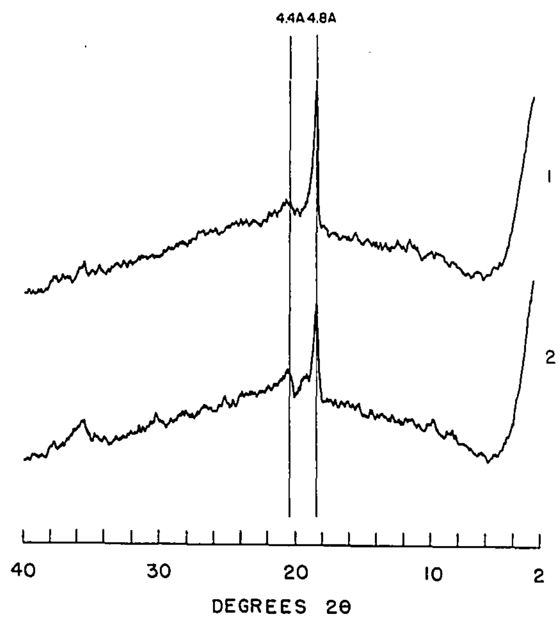

FIGURE 78. TANAMALALA (A) X-RAY DIFFRACTION PATTERNS
K SATURATED, ROOM TEMP., 1) 0-5cm and 2) 15-50cm.

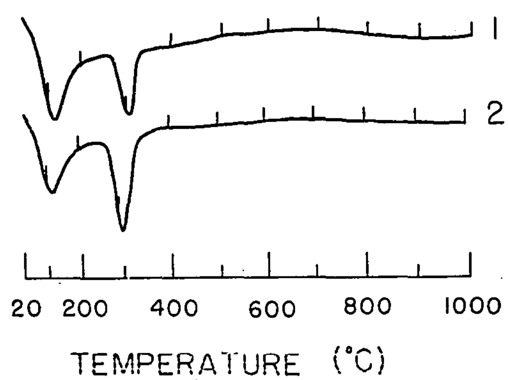

FIGURE 79. TANAMALALA (A) DIFFERENTIAL THERMAL ANALYSIS
1) 0-5cm and 2) 15-50cm.

TABLE XXVII. TANUMALALA (A) CHEMICAL ANALYSIS

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0--5	5.9	5.3	-0.6	35.60
15--50	5.9	5.9	0.0	8.90

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0--5	0.34	0.26	7.16	7.95	44.0
15--50	0.18	0.06	0.44	0.48	13.0

Depth (cm)	% Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0--5	18.18	7.60	0.96	8.0
15--50	27.18	1.50	0.18	8.0

1 meq/100g

ATU SERIES

The Atu series is a member of the fine, mixed, isothermic family of the Histic Andaquepepts.

Typifying Pedon: Atu peaty silty clay
(Colors are for moist soil)
(All textures are "apparent field texture")

0 - 10 cm -- Very dark brown (10YR 2/2) peat; weak' medium granular over weak to moderate, fine to medium subangular blocky structure; friable, nonsticky and plastic; abundant roots; many stones, faint mottling on ped surfaces; clear wavy boundary.

10 - 30 cm -- Dark brown (10YR 3/3) stony silty clay; weak medium blocky structure; friable, nonsticky and plastic; few roots; weak faint mottles; some tonguing of A into B.

Type Location: Island of Upolu. Two hundred and fifty yards above correl on Westex road, Tanumalala.

Setting: The Atu soils are formed on pahoehoe lava and ash material belonging to the lefaga volcanics. These soils occur principally on the uplands on the western section of Upolu. Elevation is approximately 1595 feet. The mean annual rainfall varies from 160 to 175 inches. The mean annual temperature is 72°F.

Drainage and Permeability: Somewhat poorly to poorly drained. Moderate permeability.

Use and Vegetation: Pasture, few aava trees, and mile-a-minute weed.

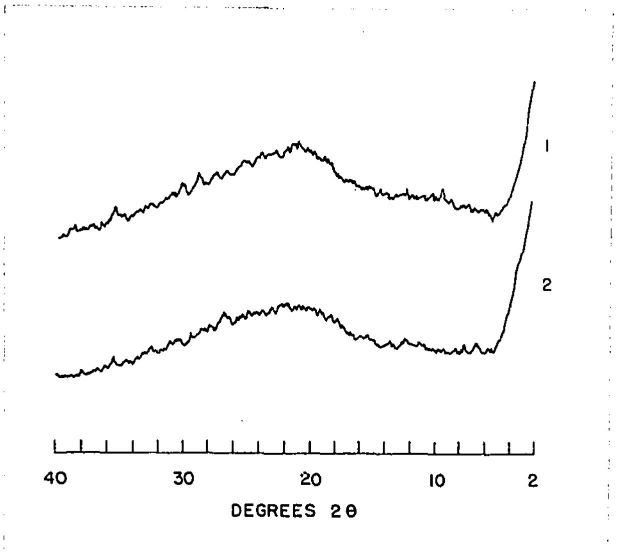

FIGURE 80. ATU X-RAY DIFFRACTION PATTERNS
K SATURATED, ROOM TEMP., 1) 0-10cm
and 2) 10-30cm.

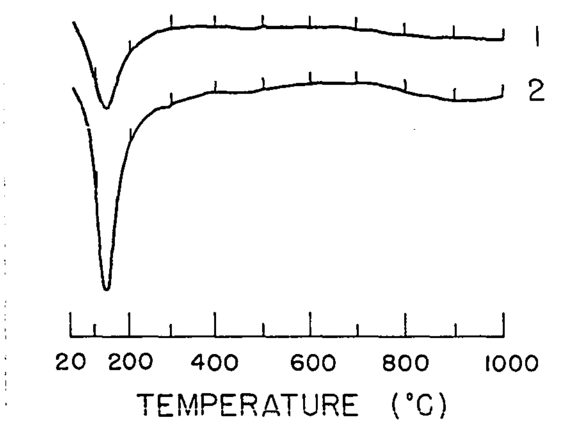

FIGURE 81. ATU DIFFERENTIAL THERMAL ANALYSIS
1) 0-10cm and 2) 10-30cm.

TABLE XXVIII. ATU CHEMICAL ANALYSIS

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-10	5.5	5.1	-0.4	87.80
10-30	5.7	5.0	-0.7	76.08

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-10	0.33	1.06	30.68	13.50	52.0
10-30	0.39	0.28	8.17	3.06	16.0

Depth (cm)	%Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-10	7.86	22.00	2.46	9.0
10-30	11.47	18.18	1.41	13.0

1 meq/100g

MAUGA SERIES

The Mauga series is a member of the clayey-skeletal, mixed, isothermic family of the Histic Humitropepts.

Typifying Pedon: Mauga stony silty clay
(Colors are for moist soil)
(All textures are "apparent field textures")

0 - 15 cm -- Very dark brown (7.5YR 2/2) stony silty clay; strong medium granular structure; friable, slightly sticky, plastic; abundant roots; many stones.

15 - 30 cm -- Very dark brown (10YR 2/2) silty clay; moderate medium granular structure; slightly sticky, plastic; abundant roots; many stones (approx. 20 cm in diameter).

30 - 60 cm -- Dark brown (10YR 3/3) silty clay loam; weak coarse blocky structure; very friable, slightly sticky, plastic; few roots; on parent rock.

Type Location: Island of Savi'i. Three and one-half miles south of Aopo village on the Aopo Track.

Setting: The Mauga soils are formed on lavas belonging to the Mulifanua volcanics. They generally have an elevation ranging from 3000 to 4000 feet. The mean annual rainfall varies from 170 to 190 inches. Mean annual temperature varies from 72 to 70°F. The surface is generally very stony. The average slope is 12%.

Drainage and Permeability: Well drained; moderately rapid permeability.

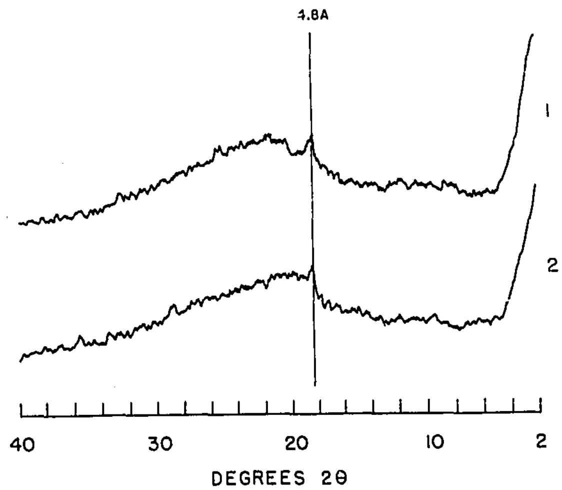

FIGURE 82. MAUGA X-RAY DIFFRACTION PATTERNS K SATURATED, ROOM TEMP., 1) 0-15cm and 2) 30-60cm.

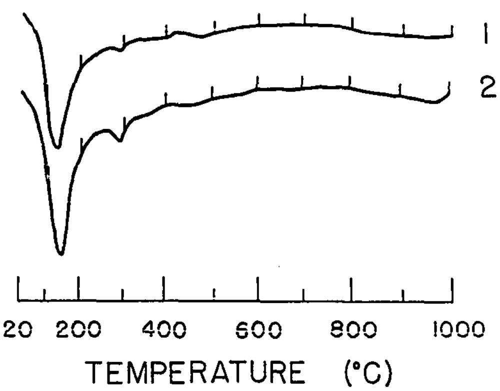

FIGURE 83. MAUGA DIFFERENTIAL THERMAL ANALYSIS 1) 0-15cm and 2) 30-60cm.

TABLE XXIX. MAUGA CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C[1]
0--30	5.7	5.1	-0.6	85.46
30--60	6.1	5.5	-0.6	62.06

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0--30	0.26	0.43	11.90	5.07	21.0
30--60	0.08	0.11	5.82	3.23	15.0

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0--30	10.09	20.68	1.61	13.0
30--60	12.98	13.54	1.02	13.0

1 meq/100g

SALEGA SERIES

The Salega series is a member of the thixotropic, isothermic family of the Typic Hydrandepts.

Typifying Pedon: Salega loam.

0 - 2.5cm -- Very dusky red (2.5YR 2/2) peaty loam; strong fine granular structure; friable; abundant roots; few stones; abrupt clear boundary.

2.5 - 23 cm -- Dark reddish brown (5YR 3/3) silty clay; weak to moderate, fine to medium subangular blocky structure; friable, nonsticky, plastic, and smeary; many roots; few stones; smooth clear boundary.

23 - 40 cm -- Dark brown (7.5YR 3/4) silty clay; weak fine to medium subangular blocky structure; friable, slightly sticky, plastic, and smeary; few roots; many stones; gradual smooth boundary.

40 - 71 cm -- Dark brown (7.5YR 4/4) clay loam; massive structure; firm, sticky, plastic, and smeary, abundant stones.

Type Location: Island of Savai'i. On Aopo tract almost one-quarter mile above fault scarp and above and north of taro patch.

Setting: The Salega soils are formed in ash and scoria belonging to the Mulifunia volcanics. The mean annual rainfall varies from 175 to 200 inches. The mean annual temperature is 69°F. Elevation is approximately 4,000'.

Drainage and Permeability: Somewhat poorly drained, moderately slow permeability.

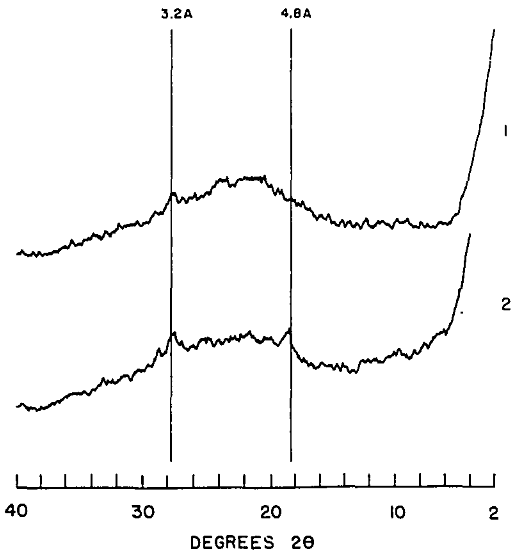

FIGURE 84. SALEGA X-RAY DIFFRACTION PATTERNS
K SATURATED, ROOM TEMP., 1) 0-23cm and
2) 23-71cm.

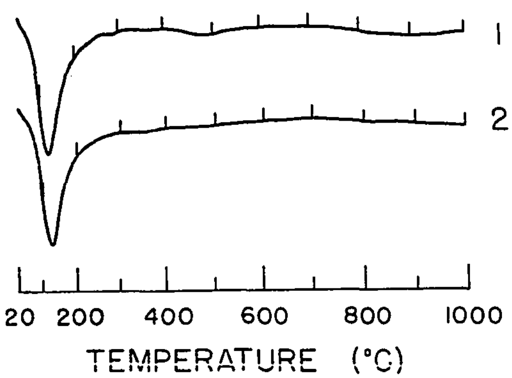

FIGURE 85. SALEGA DIFFERENTIAL THERMAL ANALYSIS
1) 0-23cm and 2) 23-71cm.

TABLE XXX. SALEGA CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-23	5.0	4.6	-0.4	78.92
23-40	5.5	5.1	-0.4	67.08

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-23	0.54	0.45	1.24	1.12	4.00
23-40	0.24	0.06	TV	0.25	0.00

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-23	5.67	18.42	1.24	14
23-40	4.88	12.17	0.88	14

1 meq/100g

MOAMOA SERIES

The Moamoa series is a member of the clayey-skeletal, oxidic, isohyperthermic family of the Oxic Dystropepts.

Typifying Pedon: Moamoa silty clay loam.

0 - 20 cm -- Dark brown (10YR 3/3) silty clay loam; strong, fine to medium granular structure; friable, nonsticky and nonplastic; many roots; few small stones; abrupt smooth boundary.

20 - 46 cm -- Dark brown (10YR 3/3) gritty silty loam; weak, very fine to fine subangular blocky structure; friable, nonsticky and nonplastic; few roots; many stones (1 to 3"); gradual smooth boundary.

46 - 76 cm -- Dark yellowish brown (10YR 3/4) gritty silty loam; weak medium coarse subangular blocky structure; firm, nonsticky, nonplastic; very few roots; many stones.

Type Location: Island of Upolu. Three-fourths of a mile north of Alafua Agricultural College on Alafua road.

Setting: Moamoa soils are formed on lavas belonging to the Salani volcanics. The mean annual rainfall is 100 to 130 inches. The mean annual temperature is 78°F. Relief is nearly level to gently sloping (3%). Elevation ranges from sea level to 500 feet.

<u>Drainage and Permeability</u>: Well drained and moderately rapid permeability.

<u>Use and Vegetation</u>: Cocoa, taro, and banana plantations.

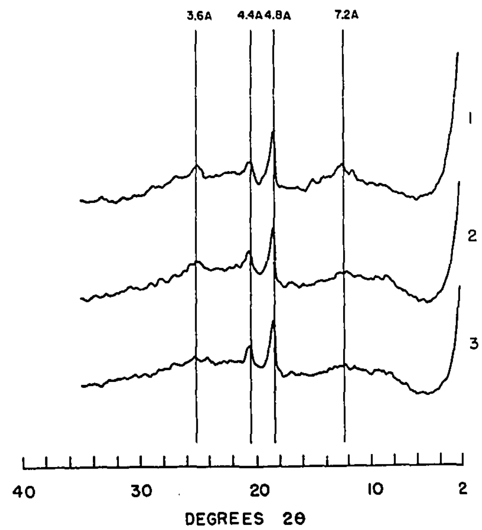

FIGURE 86. MOAMOA X-RAY DIFFRACTION PATTERNS
K SATURATED, ROOM TEMP., 1) 0-20cm,
2) 20-46cm, 3)46-76cm.

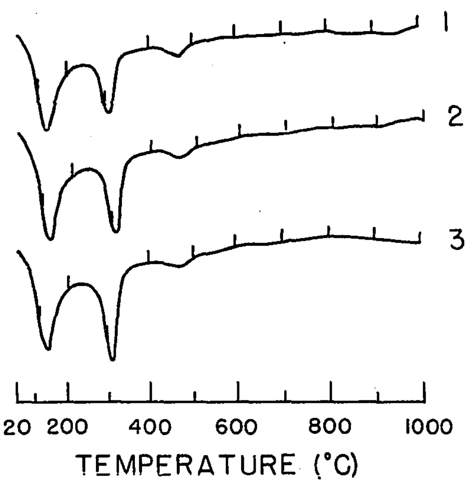

FIGURE 87. MOAMOA DIFFERENTIAL THERMAL ANALYSIS
1) 0-20cm, 2) 20-46cm, 3)46-76cm.

TABLE XXXI. MOAMOA CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-20	5.4	5.2	-0.2	32.95
20-46	5.5	5.5	0.0	26.62
46-76	6.0	6.2	0.2	25.96

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-20	0.18	0.16	2.06	1.20	11.00
20-46	0.12	0.11	0.61	0.44	5.00
46-76	0.12	0.14	0.71	0.36	5.00

Depth (cm)	%Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-20	20.16	3.94	0.36	11.00
20-46	22.14	1.83	0.18	10.00
46-76+	22.78	0.82	0.11	8.00

1 meq/100g

FALEALILI SERIES

The Falealili series is a member of the clayey-skeletal, oxidic, isohyperthermic family of the Oxic Dystropepts.

Typifying Pedon: Falealili stony clay
(Colors are for moist soil)
(All textures are "apparent field textures")

0 - 15 cm -- Very dark brown (10YR 2/2) stony clay; nonsticky and nonplastic.

15 - 50 cm -- Dark brown (10YR 3/3) stony clay; slightly sticky and slightly plastic.

Type Location: Island of Upolu. Four miles west of Lotofaga village.

Setting: The Falealili soils are formed on lavas belonging to the Salani volcanics. Elevation ranges from sea level to 750 feet. The mean annual rainfall varies from 120 to 140 inches. The mean annual temperature is 78°F. The surface is very stony.

Drainage and Permeability: Well drained; rapid permeability.

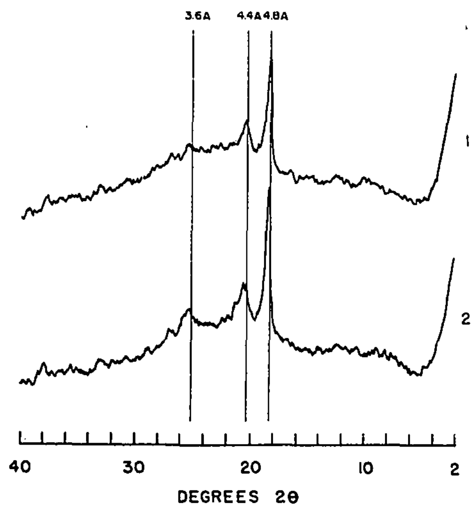

FIGURE 88. FALEALILI X-RAY DIFFRACTION PATTERNS
K SATURATED, ROOM TEMP., 1) 0-15cm,
2) 15-50cm.

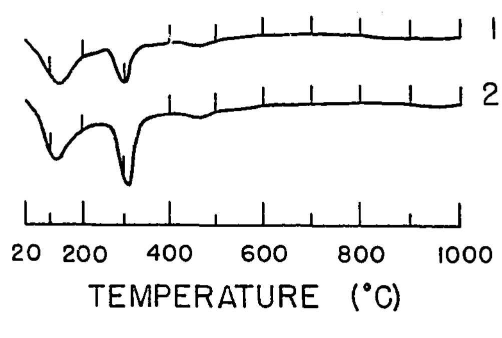

FIGURE 89. FALEALILI DIFFERENTIAL THERMAL ANALYSIS
1) 0-15cm, 2) 15-50cm.

TABLE XXXII. FALEALILI CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-15	5.7	4.9	-0.8	31.20
15-50	5.7	5.2	-0.5	16.20

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-15	0.73	0.38	7.28	5.97	46.00
15-50	0.19	0.04	2.29	1.01	22.00

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-15	9.69	7.80	0.69	11.00
15-50	13.91	2.30	0.21	11.00

1 meq/100g

FAGAGA SERIES

The Fagaga series is a member of the clayey-skeletal, oxidic, isohyperthermic family of the Oxic Dystropepts.

Typifying Pedon: Fagaga very stony clay.

0 - 8 cm -- Dark brown (10YR 3/3) very stony gritty silty clay; strong fine to medium granular to subangular blocky structure; nonsticky and plastic; very stony; clear smooth boundary.

8-25 cm -- Very dark grayish brown (10YR 3/2) very stony gritty silty clay; weak to moderate, fine to medium subangular blocky structure; friable to firm, nonsticky and plastic; moderate unweathered stones up to 3" in diameter; clear irregular boundary.

25 - 60 cm -- Brown (10YR 4/3) stony silty clay; weak fine to medium blocky structure; friable, non-stones up to 3" in diameter.

Type Location: Island of Upolu. One and one-half miles below Aiona sawmill on Afiamalu - Siumu road.

Setting: Fagaga soils are formed on lava belonging to the Salani volcanics. Physiographically they occur on gently rolling surfaces. The mean annual rainfall varies from 150 to 175 inches. The mean annual temperature is 72°F.

Elevation ranges from 500 to 1,000 feet.

Drainage and Permeability: Well drained and rapid permeability

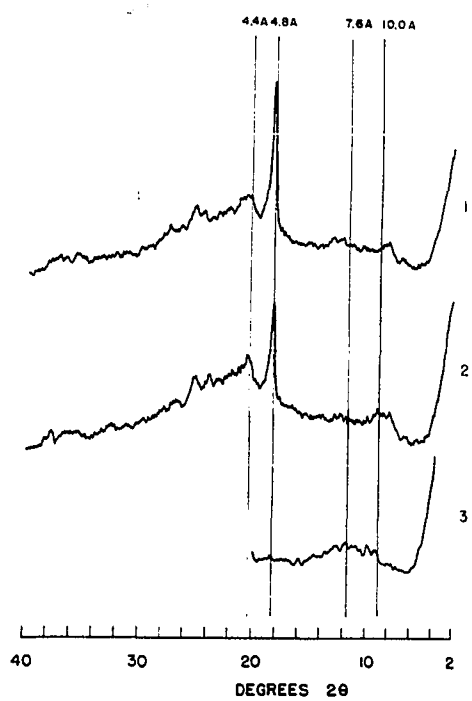

FIGURE 90. FAGAGA X-RAY DIFFRACTION PATTERNS
1) 0-25cm, K SAT., 2) 25-60cm, K SAT.,
3) 25-60cm, HEATED TO 350°C.

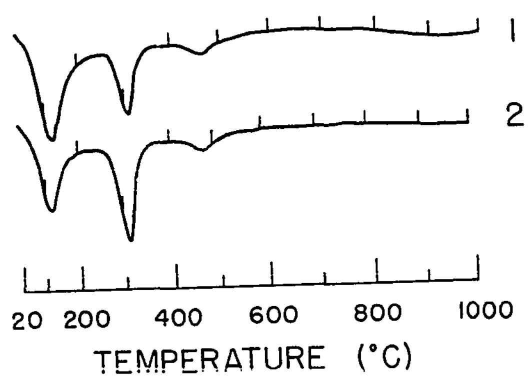

FIGURE 91. FAGAGA DIFFERENTIAL THERMAL ANALYSIS
1) 0-25cm, 2) 25-60cm.

TABLE XXXIII. FAGAGA CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-8	5.6	5.0	-0.6	43.29
25-60	5.7	5.3	-0.4	23.75

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-8	0.27	0.32	7.29	4.39	28.00
25-60	0.20	0.09	0.90	0.68	8.00

Depth (cm)	% Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-8	13.66	9.95	0.70	13.00
25-60	17.51	4.40	0.24	16.00

1. meq/100g

SOLOSOLO SERIES

The Solosolo series is a member of the fine oxidic isothermic family of the Oxic Humitropepts.

Typifying Pedon: Solosolo silty clay

0 - 8 cm -- Dark brown (10YR 3/3) silty clay; weak medium to coarse granular structure; friable, slightly sticky, and plastic; few roots; smooth clear boundary.

8 - 30 cm -- Dark brown (10YR 3/3) ,gritty silty clay; weak to moderate, fine to medium subangular blocky structure; friable, slightly sticky, and plastic; few roots; clear smooth boundary.

30 - 58 cm -- Dark brown (10YR 3/3) silty clay loam; weak and moderate, coarse blocky to prismatic structure; friable, slightly sticky, and plastic; smooth gradual boundary.

58+cm -- Dark brown (10YR 3/3) silty clay; weak to moderate, medium to coarse subangular blocky structure; friable, sticky, and plastic; few thin clay skins.

(Few moderate stones in the profile. Basalt boulders throughout solum)

Type Location: Island of Upolu. Four and one-half miles from main road junction on Afiamalu road. One and three-fourth miles below wireless station at Afiamalu.

Setting: Solosolo soils are formed on lava belonging to the Salani volcanics. The mean annual rainfall varies from 150 to 170 inches. The mean annual temperature is 72°F. Relief is usually gently rolling. Elevation ranges from 1,500 to 2,200 feet.

Drainage and Permeability: Well drained and moderately rapid permeability.

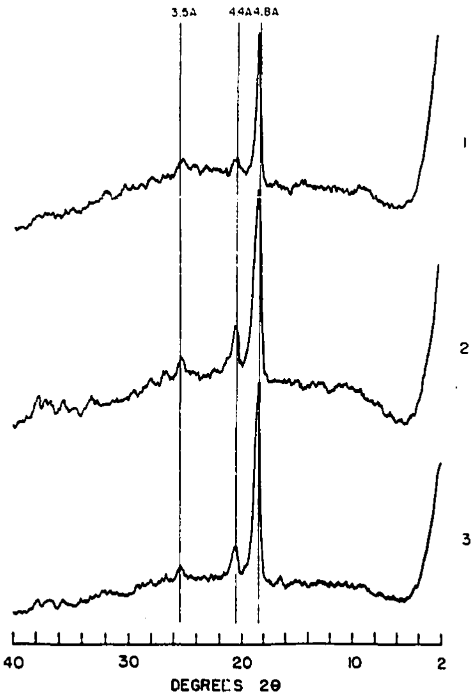

FIGURE 92. SCLOSOLO X-RAY DIFFRACTION PATTERNS
K SATURATED, ROOM TEMP., 1) 0-8cm,
2) 8-30cm, 3) 30-58cm.

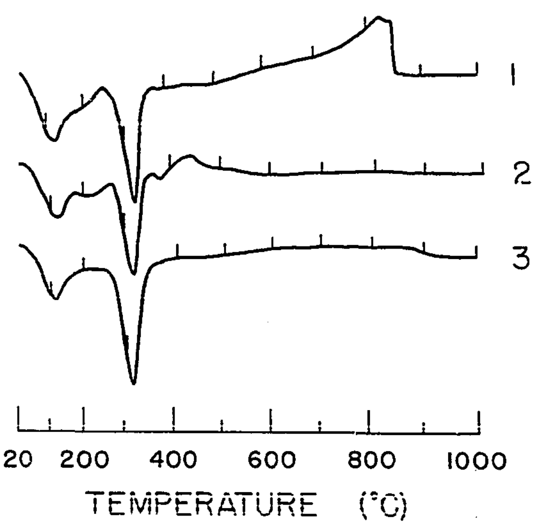

FIGURE 93. SOLOSOLO DIFFERENTIAL THERMAL ANALYSIS
1) 0-8cm, 2) 8-30cm, 3) 30-58cm.

TABLE XXXIV. SOLOSOLO CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	ΔpH	C.E.C.[1]
0-30	5.6	5.1	-0.5	26.91
30-50	5.9	6.0	0.1	12.68
61-71	5.9	6.0	0.1	11.36

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-30	0.07	0.12	3.24	1.80	19.4
30-50	0.05	0.02	Tr	0.11	1.4
61-71	0.05	0.02	Tr	0.08	1.3

Depth (cm)	%Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-30	17.96	6.13	0.46	13.00
30-50	19.90	2.09	0.10	21.00
61-71	19.35	1.55	0.06	26.00

1 meq/100g

ETIMULI SERIES

The Etimuli series is a member of the fine oxidic isothermic family of the Oxic Humitropepts.

Typifying Pedon: Etimuli silty clay

0 - 23 cm -- Brown (10YR 4/3) silty clay; moderate medium subangular blocky structure; friable, nonsticky, and plastic; clear smooth boundary.

23 - 51 cm -- dark brown (7.5YR 3/4) slightly gritty silty clay; moderate to strong, fine to medium subangular blocky structure; friable, sticky, and plastic; thin continuous clay skins;smooth gradual boundary.

51^{+}cm -- Very dark grayish brown (10YR 3/2) to dark brown (7.5YR 3/4) silty clay; moderate medium to coarse subangular blocky structure; friable, sticky, and plastic; large amount of saprolite. (Very thin organic layer on surface horizon, ¼ to ½" thick).

Type Location: Island of Upolu. Two miles south of Mafa Pass.

Setting: The Etimuli series are formed on the Mulifunia volcanics. These soils occur on gently sloping uplands with very little dissection. The mean annual rainfall is 72°F. [Temperature at a 28" depth on 6/20/67 was 76°F] Elevation ranges from 750 to 1800 feet.

Drainage and Permeability: Well drained with moderate permeability.

Use and Vegetation: Few banana plantations, banana, paragrass, kapok, breadfruit and tree fern.

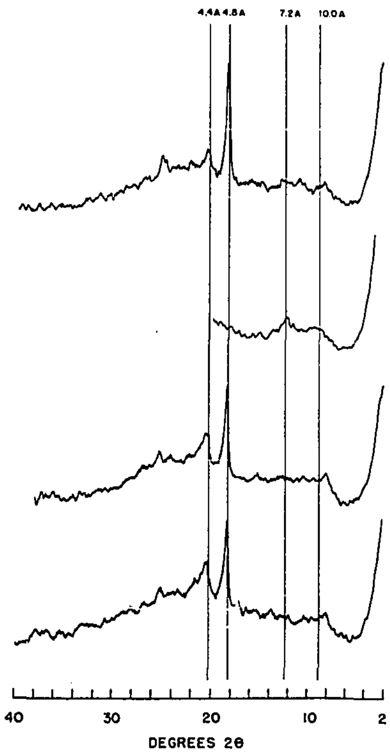

FIGURE 94. ETIMULI X-RAY DIFFRACTION PATTERNS
1) 0-23cm K SAT., ROOM TEMP., 2) HEATED TO 350°C, 3) 23-51cm K SAT., ROOM TEMP., 4) 51+cm K SAT., ROOM TEMP.

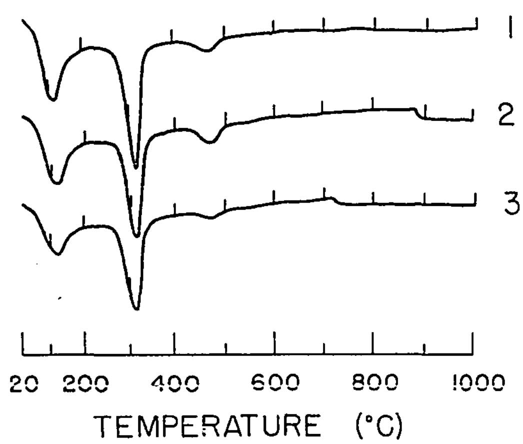

FIGURE 95. ETIMULI DIFFERENTIAL THERMAL ANALYSIS
1) 0-23cm, 2) 23-51cm, 3) 51+cm.

TABLE XXXV. ETIMULI CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-23	5.0	4.8	-0.2	24.55
23-51	5.1	5.4	0.3	15.32
56-71	5.4	5.7	0.3	12.25

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-23	0.26	0.17	0.89	0.77	8.00
23-51	0.18	0.07	Tr	0.05	2.00
56-71	0.09	0.07	0.22	0.29	6.00

Depth (cm)	%Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-23	20.93	5.06	0.40	13.00
23-51	22.48	1.23	0.10	12.00
56-71	22.50	0.67	0.05	13.00

1 meq/100g

AFIAMALU SERIES

The Afiamalu series is a member of the fine, oxidic, isothermic family of the Oxic Humitropepts.

Typifying Pedon: Afiamalu silty clay
(Colors are for moist soil)
(All textures are "apparent field textures")

0 - 10 cm -- Brown to dark brown (10YR 4/3) silty clay; moderate medium granular structure; friable, nonsticky, plastic; very few fine concretions; smooth clear boundary.

10 - 30 cm -- Brown to dark brown (10YR 4/3) silty clay; weak to moderate, fine to medium subangular blocky structure; friable, slightly sticky, plastic; few concretions and weathered rock; smooth clear boundary.

30 - 60 cm -- Brown to dark brown (7.5YR 4/4) gritty clay or clay loam; strong medium to coarse subangular blocky structure; friable to firm, sticky, plastic; few concretions and fine weathered rocks; contineous thin clay skins; smooth gradual boundary.

60 - 99 cm -- Brown to dark brown (7.5YR 4/4) gritty clay; strong coarse subangular blocky and blocky structure; firm, sticky, plastic; contineous clay skins of yellowish red (5YR 4/6) color.

Type Location: Tiavi Saddle, Island of Upolu. At Alafua College experimental plots.

Setting: The Afiamalu soils are formed in scoria and ash belonging to the Salani volcanics. Elevation ranges from 2000 to 2500 feet. Mean annual rainfall is usually greater than 200 inches. Mean annual temperature is 69°F.

Drainage and Permeability: Moderately well drained; moderate permeability.

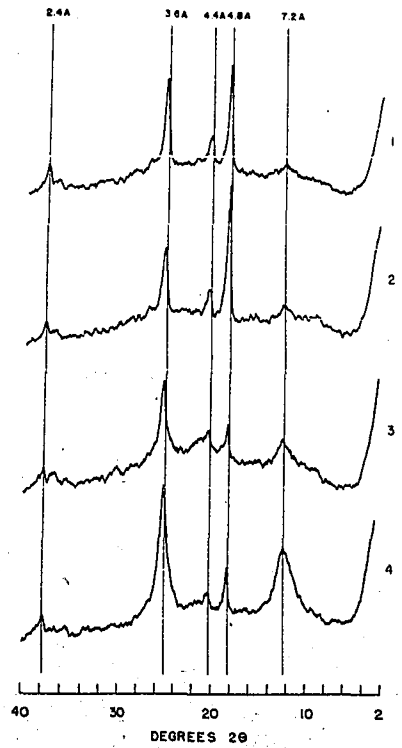

FIGURE 96. AFIAMALU X-RAY DIFFRACTION PATTERNS K SATURATED, ROOM TEMP., 1) 0-10cm, 2) 10-30cm, 3) 30-60cm, 4) 60-99cm.

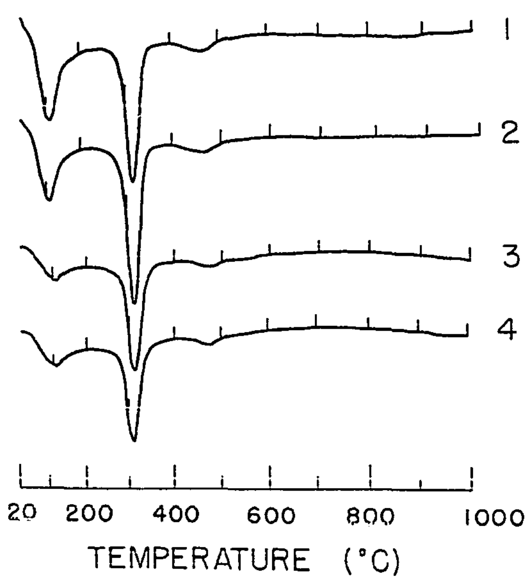

FIGURE 97. AFIAMALU DIFFERENTIAL THERMAL ANALYSIS 1) 0-10cm, 2) 10-30cm, 3) 30-60cm, 4) 60-99cm.

TABLE XXXVI. AFIAMALU CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C[1]
0-10	5.1	4.5	-0.6	26.01
10-35	5.3	4.6	-0.7	21.57
35-60	5.7	6.0	0.3	6.52
60-99	5.5	6.1	0.6	4.68

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-10	0.32	0.28	0.58	0.66	7.00
10-35	0.19	0.12	0.12	0.21	3.00
35-60	0.05	--	--	0.10	2.00
60-99	0.06	0.02	--	0.14	5.00

Depth (cm)	% Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-10	24.66	8.45	0.54	16.00
10-35	15.63	6.49	0.38	17.00
35-60	29.62	0.86	0.06	14.00
60-99	31.37	0.63	0.03	21.00

1 meq/100g

FIAMOE SERIES

The Fiamoe series is a member of the fine, oxidic, isothermic family of the Oxic Dystropepts.

Typifying Pedon: Fiamoe silty clay

(Colors are for moist soil)

(All textures are "apparent field textures")

0 - 13 cm -- Dark brown (10YR 3/3) silty clay; strong fine to medium granular and subangular blocky structure; very friable, nonsticky, plastic; many roots; few cinders (2 to 7cm) clear smooth boundary.

13 - 43 cm -- Brown to dark brown (10YR 4/3) clay; weak medium to coarse subangular blocky structure; friable, sticky, plastic; few roots; clear smooth boundary.

43 - 61 cm -- Dark grayish brown (10YR 4/2) clay; moderate fine to medium subangular blocky structure; friable, sticky, very plastic; few roots; few large basalt boulders.

Type Location: Island of Upolu. Tiavi Saddle between Afiamalu wireless station and the Alafua College experimental plots.

Setting: The Fiamoe soils are formed in lava overlain by ash and scoria belonging to the Salani volcanics. Elevation is approximately 2100 feet. Mean annual rainfall is usually greater than 200 inches. Mean annual temperature is $69^{o}F$.

Drainage and Permeability: Moderately well drained; moderate permeability.

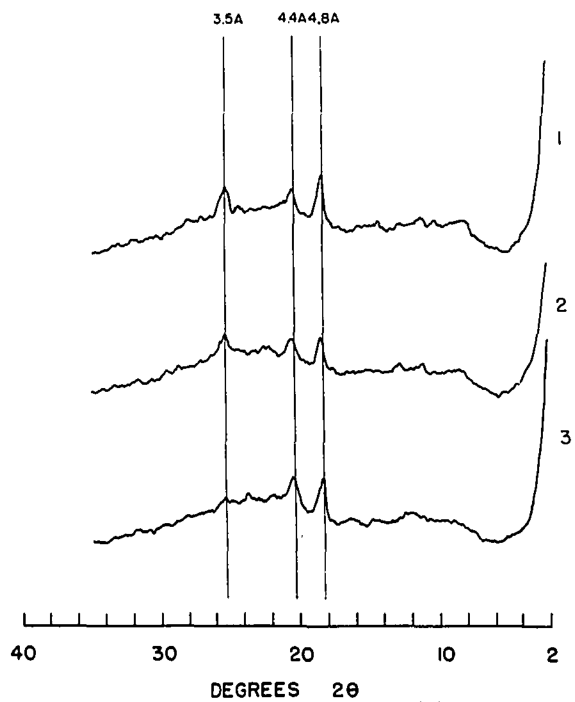

FIGURE 98. FIAMOE X-RAY DIFFRACTION PATTERNS. K SAT. ROOM TEMP., 1) 0-13cm, 2) 13-43cm, 3) 43-61cm.

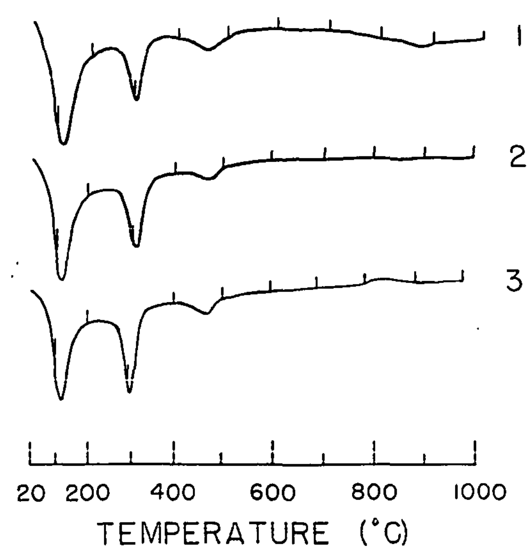

FIGURE 99. FIAMOE DIFFERENTIAL THERMAL ANALYSIS 1) 0-13cm, 2) 13-43cm, 3) 43-61cm.

TABLE XXXVII. FIAMOE CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-13	5.4	4.8	-0.6	46.61
13-43	5.1	5.3	0.2	29.07
43-61	5.2	5.4	0.2	24.10

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-13	0.27	0.39	3.09	1.56	11.39
13-43	0.13	0.16	0.41	0.24	0.00
43-61	0.20	0.11	0.31	0.24	0.00

Depth (cm)	%Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-13	22.08	11.97	0.93	13.00
13-43	23-62	4.56	0.34	13.00
43-60	18.88	1.62	0.11	15.00

1 meq/100g

TIAVI SERIES

The Tiavi series is a member of the fine, mixed, oxidic family of the Oxic Humitropepts.

Typifying Pedon: Tiavi silty clay
(Colors are for moist soil)
(All textures are "apparent field texture")

0 - 10 cm -- Reddish brown (5YR 4/4) to yellowish red (5YR 4/6) stony silty clay; slightly sticky, slightly plastic.

10 - 25 cm -- Yellowish red (5YR 4/6) stony silty clay; slightly sticky, slightly plastic.

45 - 76 cm -- Brown (7.5YR 5/2) sandy clay; slightly sticky, slightly plastic; soft weathered rock.

Type Location: Island of Upolu. Flank of Lohoanea cone.

Setting: The Tiavi soils are formed in pahoehoe lava belonging to the Salani volcanics. Elevation ranges from 2000 to 2500 feet. Mean annual rainfall is usually greater than 200 inches. Mean annual temperature is 69°F.

Drainage and Permeability: Moderately well drained; moderate permeability.

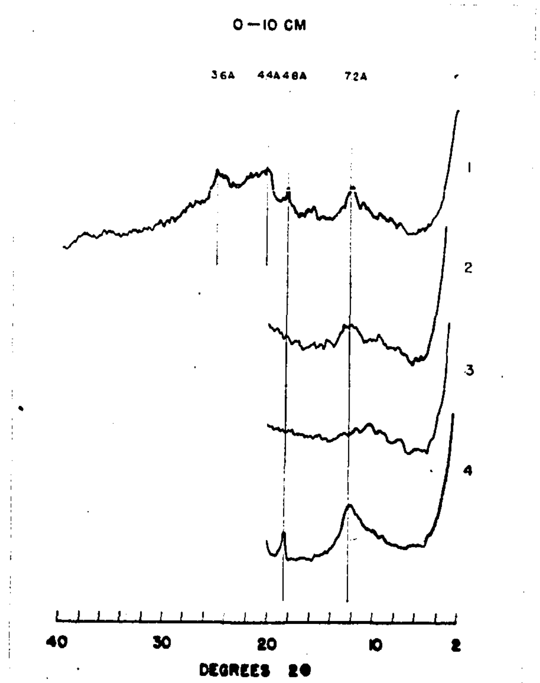

FIGURE 100. TIAVI X-RAY DIFFRACTION PATTERNS 0-10cm,
1) K SAT., ROOM TEMP., 2) 350°C, 3) 550°C,
4) Mg GLYCOLATED.

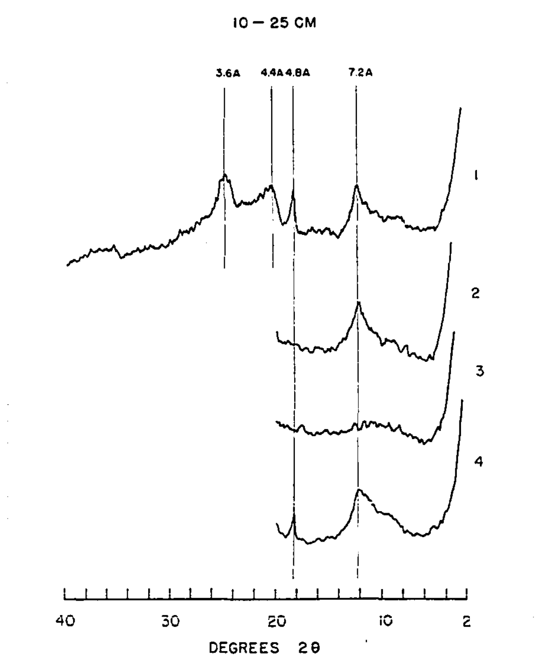

FIGURE 101. TIAVI X-RAY DIFFRACTION PATTERNS 10-25cm,
1) K SAT., ROOM TEMP., 2) 350°C, 3) 550°C,
4) Mg GLYCOLATED.

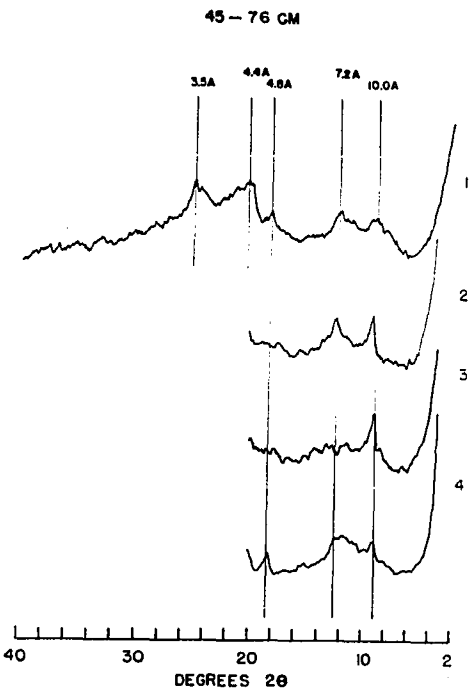

FIGURE 102. TIAVI X-RAY DIFFRACTION PATTERNS 45-76cm, 1) K SAT., ROOM TEMP., 2) 350°C, 3) 550°C, 4) Mg GLYCOLATED.

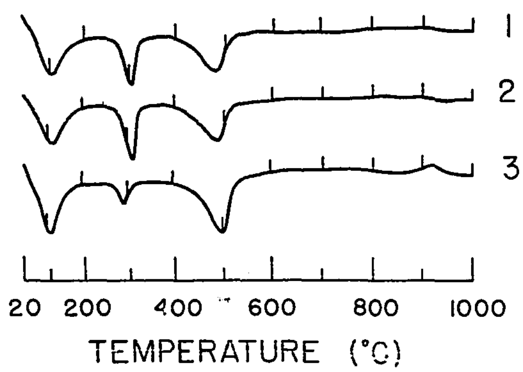

FIGURE 103. TIAVI DIFFERENTIAL THERMAL ANALYSIS 1) 0-10cm, 2) 10-25cm, 3) 45-76cm.

TABLE XXXVIII. TIAVI CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	ΔpH	C.E.C.[1]
0-10	5.1	4.4	-0.7	22.70
10-25	5.0	4.3	-0.7	17.90
$46-76^{+}$	5.4	4.5	-0.9	14.20

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-10	0.24	0.40	0.22	1.18	8.00
10-25	0.43	0.29	0.65	2.03	20.00
$46-76^{+}$	0.32	0.02	0.22	0.90	10.00

Depth (cm)	%Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-10	18.63	6.50	0.42	16.00
10-25	17.66	4.30	0.30	14.00
46-76	20.48	1.30	0.15	9.00

1 meq/100g

VAIPOULI SERIES

The Vaipouli series is a member of the fine, gibbsitic, isohyperthermic family of the Typic Haplorthoxs.

Typifying Pedon: Vaipouli silty clay

0 - 20 cm -- Brown (7.5YR 4/4) silty clay; strong fine to medium subangular blocky structure; friable, slightly sticky, and slightly plastic; many roots; many small stones; gradual smooth boundary.

20 - 53 cm -- Brown (7.5YR 4/4) clay loam; massive to moderate very fine subangular blocky structure; friable, slightly sticky, and plastic; few roots; gradual smooth boundary.

53 - 79 cm -- Brown (7.5YR 4/4) clay loam; massive to moderate blocky structure; firm, sticky, and plastic; no roots; clear smooth boundary.

79 - 104cm -- Reddish brown (5YR 4/4) clay loam; massive to moderate blocky structure; firm, sticky' and plastic; no roots; clear smooth boundary.

104^{+}cm - Reddish brown (5YR 4/4) clay loam; weak coarse blocky structure; firm, slightly sticky, and plastic; no roots.

Type Location: Island of Savai'i. One-half mile above cliff near Manase village.

Setting: The Vaipouli soils are formed on the Fagaloa volcanics. These soils occur on gently sloping surfaces (2%). Elevation is approximately 175 feet. Mean annual rainfall varies from 100 to 130 inches. Mean annual temperature is 78°F.

Drainage and Permeability: Well drained, moderately rapid permeability.

Use and Vegetation: Coconut plantations; Maota and Toi - disturbed forest.

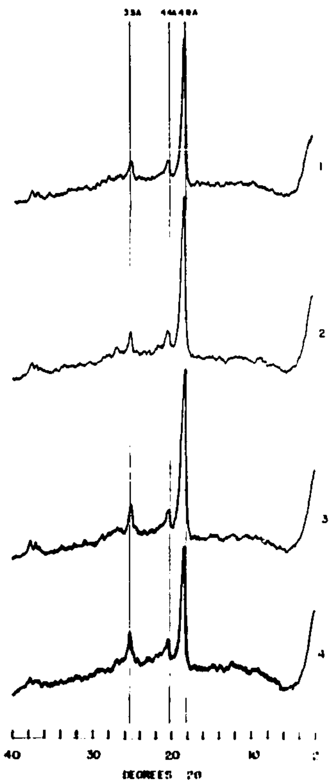

FIGURE 104. VAIPOULI X-RAY DIFFRACTION PATTERNS K SAT., ROOM TEMP., 1) 0-20cm, 2) 20-53cm, 3) 53-79cm, 4) 79-104cm.

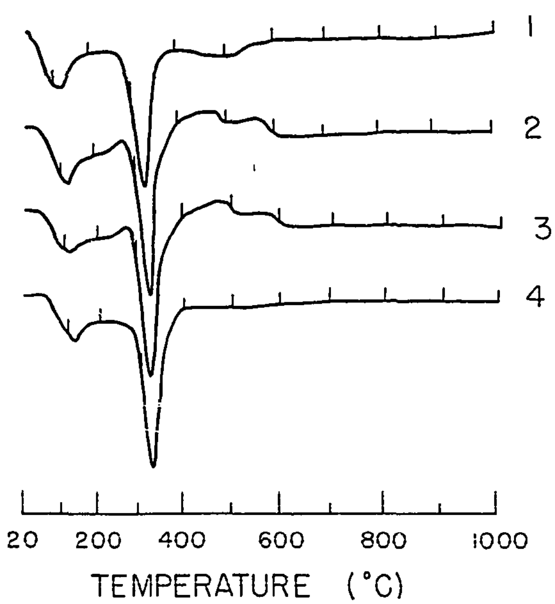

FIGURE 105. VAIPOULI DIFFERENTIAL THERMAL ANALYSIS 1) 0-20cm, 2) 20-53cm, 3) 53-79cm, 4) 79-104cm.

TABLE XXXIX. VAIPOULI CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-20	5.9	5.5	-0.4	21.40
20-53	5.8	5.6	-0.2	11.38
53-79	5.6	5.7	0.1	11.16
79-104	5.9	6.3	0.4	5.78

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-20	0.09	0.14	5.1	3.03	39.00
20-53	0.12	0.01	Tr	0.36	4.00
53-79	0.06	0.03	Tr	0.11	2.00
79-104	0.04	--	Tr	0.02	1.00

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-20	19.35	5.78	0.45	13.00
20-53	21.66	2.52	0.15	17.00
53-79	21.81	1.87	0.13	14.00
79-104	25.79	0.21	0.02	11.00

1 meq/100g

SAUAGA SERIES

The Sauaga series is a member of the very fine, halloysitic isohyperthermic family of the Oxic-Ultic Dystropepts.

Typifying Pedon: Sauaga clay

0 - 15 cm -- Dark reddish brown (5 YR 3/3) clay; moderately plastic.

15 - 30 cm -- Reddish brown (5YR 4/4) clay; moderately plastic; compact.

Type Location: Island of Upolu. Two miles west of Falese'ela village.

Setting: The Sauaga soils are formed in residium from lava of the Fagaloa volcanics. Elevation ranges from sea level to 1000 feet. Rainfall varies from 110 to 150 inches. Mean annual temperature is 78^{o}F. These soils experience one moderately dry month.

Drainage and Permeability: Well drained; moderate permeability.

SAUAGA SERIES

The Sauaga series is a member of the very fine, halloysitic isohyperthermic family of the Oxic-Ultic Dystropepts.

Typifying Pedon: Sauaga clay

0 - 15 cm -- Dark reddish brown (5 YR 3/3) clay; moderately plastic.

15 - 30 cm -- Reddish brown (5YR 4/4) clay; moderately plastic; compact.

Type Location: Island of Upolu. Two miles west of Falese'ela village.

Setting: The Sauaga soils are formed in residium from lava of the Fagaloa volcanics. Elevation ranges from sea level to 1000 feet. Rainfall varies from 110 to 150 inches. Mean annual temperature is 78^{o}F. These soils experience one moderately dry month.

Drainage and Permeability: Well drained; moderate permeability.

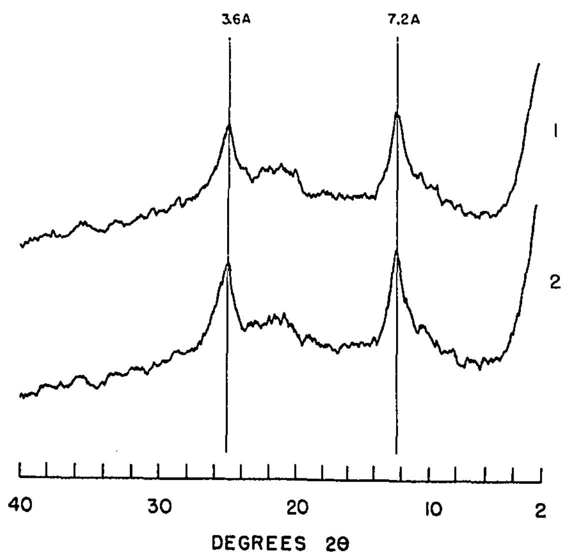

FIGURE 106. SAUAGA X-RAY DIFFRACTION PATTERNS K SAT., ROOM TEMP., 1) 0-15cm, 2) 15-30cm.

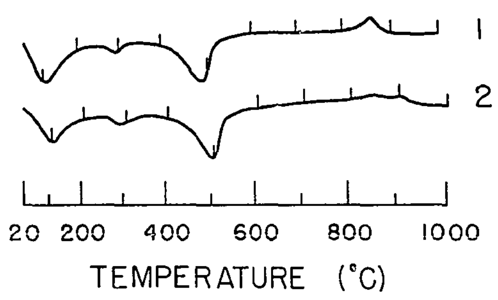

FIGURE 107. SAUAGA DIFFERENTIAL THERMAL ANALYSIS 1) 0-15cm, 2) 15-30cm.

TABLE XXXX. SAUAGA CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-15	5.3	4.7	-0.6	24.60
15-30	5.2	4.5	-0.6	13.20

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-15	0.27	0.34	4.69	5.07	42.00
15-30	0.32	0.02	1.38	2.68	33.00

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-15	13.40	4.00	0.37	11.00
15-30	14.33	0.60	0.08	8.00

1. meq/100g

LUATUANU'U SERIES

The Luatuanu'u series is a member of the very fine, halloysitic, isohyperthermic family of the Oxic Humitropept.

Typifying Pedon: Luatuanu'u clay

0 - 10 cm -- Dark reddish brown (5YR 3/3) clay; strong medium subangular blocky structure; firm to friable, slightly sticky, slightly plastic; diffuse boundary.

10 - 23 cm -- Dark reddish brown (5YR 3/4) clay; weak medium blocky structure; friable to firm, slightly sticky, plastic, boundary, on soft weathered rock.

Type Location: Two and one-half miles south of Luatuanu'u village.

Setting: The Luatuanu'u soils are formed in residium from lava of the Fagaloa volcanics. These soils range in elevation from sea level to 1000 feet. Mean annual rainfall varies from 120 to 140 inches. Mean annual temperature is 78°F. Steep slopes predominate (27%). Large areas of these soils show considerable erosion.

Drainage and Permeability: Moderately well drained; slow permeability.

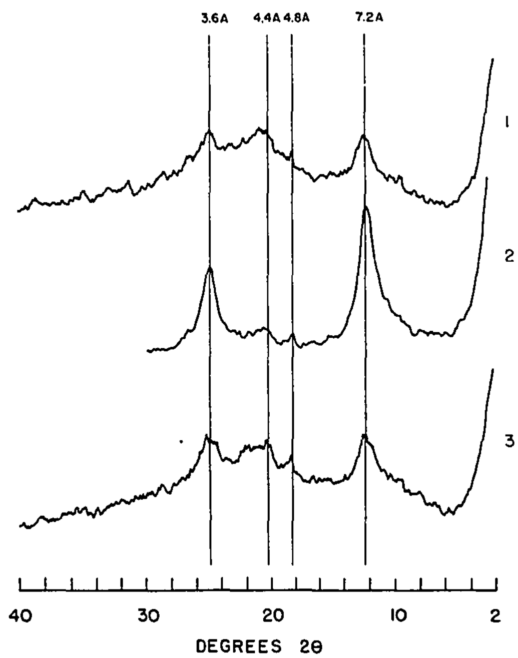

FIGURE 108. LUATUANU'U X-RAY DIFFRACTION PATTERNS 0-10cm 1) K SAT., ROOM TEMP., 2) 350°C, 3) 10-23cm K SAT., ROOM TEMP.

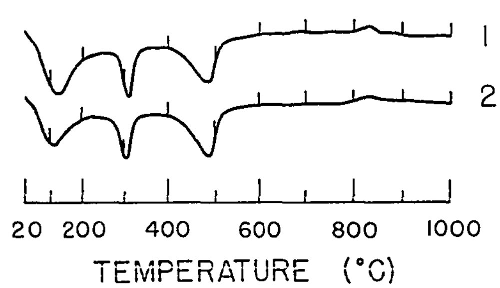

FIGURE 109. LUATUANU'U DIFFERENTIAL THERMAL ANALYSIS 1) 0-10cm, 2) 10-23cm.

TABLE XXXXI. LUATUANU'U CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-10	4.8	4.2	-0.6	28.30
10-23	5.0	4.4	-0.6	17.50

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-10	0.27	0.39	0.99	2.30	14.00
10-23	0.17	0.16	0.01	1.02	8.00

Depth (cm)	% Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-10	16.45	10.80	0.55	20.00
10-23	18.77	4.70	0.28	17.00

1 meq/100g

UPOLU SERIES

The Upolu series is a member of the very fine, mixed, isothermic family of the Humoxic Tropohumults.

Typifying Pedon: Upolu Clay

(Colors are for moist soil)

(All textures are "apparent field textures")

0 - 10 cm -- Dark brown (10YR 3/3) clay weak fine to medium granular and subangular blocky structure; very friable, sticky, plastic; many fine roots; clear smooth boundary.

10 - 30 cm -- Dark brown (10YR 3/3) silty clay; moderate fine to medium subangular blocky structure; friable, sticky, plastic; common roots; gradual smooth boundary.

30 - 60 cm -- Dark brown (7.5YR 3/3) clay; strong fine to medium subangular blocky structure; firm, sticky, plastic; no roots; many continuous cutans.

Type Location: Island of Upolu. One-half mile above Alaoa power plant.

Setting: The Upolu soils are formed from residium of the Fagaloa volcanics. Elevation ranges from 500 to 2,000 feet. Rainfall varies from 150 to 200 inches. Mean annual temperature is 72°F. Upolu soils usually occur on semi-stable slopes and are not as eroded as the Luatuanu'u soils.

<u>Drainage and Permeability</u>: Moderately well drained, moderately slow permeability.

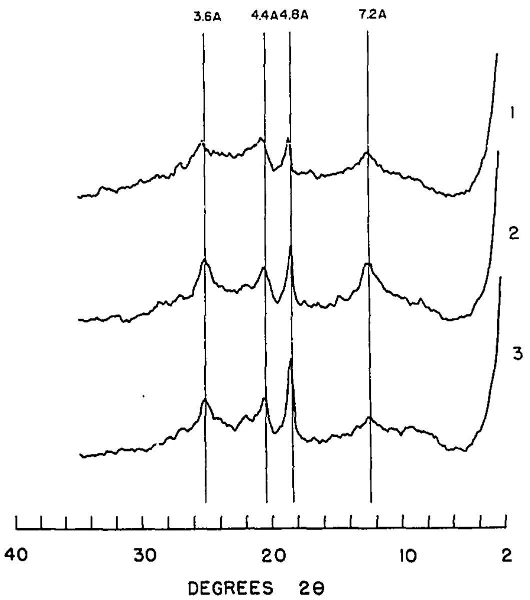

FIGURE 110. UPOLU X-RAY DIFFRACTION PATTERNS K SAT., ROOM TEMP., 1) 0-10cm, 2) 10-30cm, 3) 30-60cm.

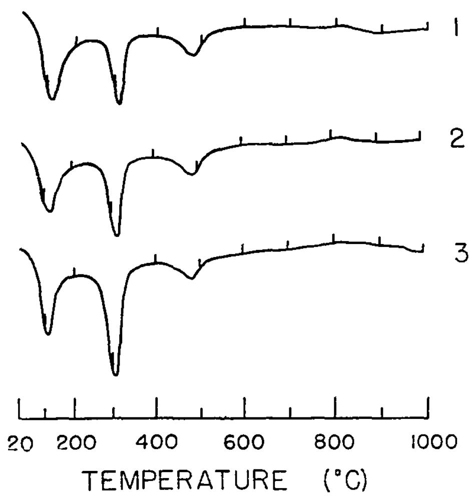

FIGURE 111. UPOLU DIFFERENTIAL THERMAL ANALYSIS 1) 0-10cm, 2) 10-30cm.

TABLE XXXXII. UPOLU CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	Δ pH	C.E.C.[1]
0-10	5.6	5.4	-0.2	39.93
10-30	6.0	5.8	-0.2	29.55
30-60+	6.5	6.4	-0.2	16.83

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	%Base Saturation
0-10	0.20	0.42	10.62	3.80	38.00
10-30	0.12	0.08	7.04	1.56	30.00
30-60+	0.11	0.08	1.73	0.32	13.00

Depth (cm)	$\%Fe_2O_3$	% Organic Carbon	% Total Nitrogen	C/N
0-10	17.28	6.59	0.55	12.00
10-30	19.36	2.59	0.21	12.00
30-60+	21.92	0.35	0.08	4.00

1 meq/100g

ALAFUA SERIES

The Alafua series is a member of the very fine, halloysitic, isohyperthermic family of the Fluventic-Oxic Dystropepts.

Typifying Pedon: Alafua clay

(Colors are for moist soil)

(All textures are "apparent field textures")

0 - 12 cm -- Dark brown (7.5YR 3/2) clay; moderate medium granular structure; friable, sticky, plastic; clear smooth boundary.

12 - 30 cm -- Dark brown (7.5YR 3/2) to dark yellowish brown (10YR 3/4) clay; weak medium subangular blocky breaking to moderate fine subangular blocky structure; friable, sticky, plastic; clear smooth boundary.

43^{+}cm --Alluvium, silty clay, firm to friable, sticky and plastic.

Type Location: Island of Upolu. Along stream near Moamoa village.

Setting: The Alafua soils are developed on alluvium derived from erosion of the Fagaloa volcanics. Mean annual temperature is 78°F. The mean annual rainfall is 130 inches. Elevation ranges from sea level to 500 feet.

Drainage and Permeability: Well drained; slow permeability.

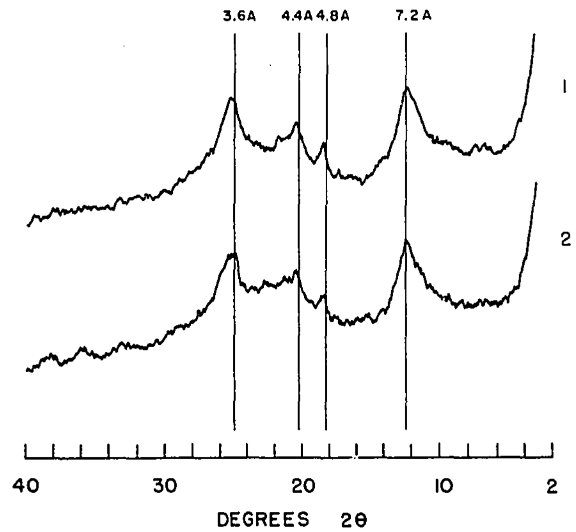

FIGURE 112. ALAFUA X-RAY DIFFRACTION PATTERNS K SAT., ROOM TEMP., 1) 0-12cm, 2) 12-30cm.

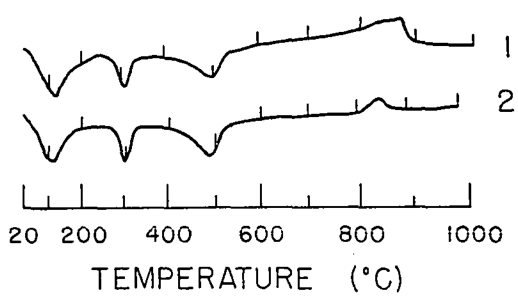

FIGURE 113. ALAFUA DIFFERENTIAL THERMAL ANALYSIS 1) 0-12cm, 2)12-30cm.

TABLE XXXXIII. ALAFUA CHEMICAL ANALYSES

Depth (cm)	pH (H_2O)	pH (KCl)	ΔpH	C.E.C.[1]
0-12	5.6	5.0	-0.6	22.65
12-30	5.5	4.9	-0.6	8.61

Depth (cm)	Na[1]	K[1]	Ca[1]	Mg[1]	% Base Saturation
0-12	0.10	0.17	7.75	5.54	60.00
12-30	0.10	0.06	4.62	3.33	94.00

Depth (cm)	%Fe_2O_3	% Organic Carbon	% Total Nitrogen	C/N
0-12	14.99	4.50	0.36	12.00
12-30	15.33	2.18	0.19	12.00

1 meq/100g

APPENDIX II

PROGRAM TO CALCULATE THE GAMMA DENSITY
PARAMETERS r AND B

```
      IMPLICIT REAL *8(A-H,O-Z)
      DIMENSION Z (100)
      COMMON R,B
C
C  A = ARITHMETIC MEAN
C  G = GEOMETRIC MEAN
C
      A = 8.8295736D0
      G = 1.466324D0
      Y = DLOG (A) - DLOG (G)
      IF (Y.GT.17.0D0) GO TO 10
      IF (Y.GE.0.5772D0) GO TO 11
      R = (((0.5000876D0+(0.1648852D0*Y))-(0.0544274D0*(Y**2)))/Y)
      GO TO 12
   11 R = ((8.898919D0+(9.059950D0*Y))+(0.9775373D0*(Y**2)))/
     1(Y*((17.79728 D0+(11.968477D0*Y))+(Y**2)))
      GO TO 12
   10 WRITE(6,13)
   13 FORMAT ('1',T10,'Y GT 17-CAN NOT EVALUATE P-DUMP')
      STOP
   12 B = A/R
      A2 = B*R
      A3 = (B**2)*R
      WRITE(6,14) A2, A3, B, R
   14 FORMAT('1',T10,'B*R =',1PD18.7//T10,'(B**2)*R =',1PD18.7
     1//T10,'B = ',1PD18.7//T10,'R = ',1PD18.7)
      XS = 0.0D0
      XI = 5.0D0
      XU = XS+XI
      N = 31
      WRITE(6,100)
  100 FORMAT('1',T10,'TABLE OF INTEGRATIONS'//T10,'LIMITS',
     1T30,'AREAS')
      WRITE(6,101) XS
  101 FORMAT('0',9X,1PD6.1)
      DO 102 J = 1,N
      XXX = COMXP(XU)
      A = DGNT GR(XS,XU,100,COMXP)
      WRITE(6,105) A,XU
  105 FORMAT('0',T25.1PD18.7//T10,1PD6.1)
      Z(J) = (XU**(R-1.0))*(DEXP(-(XU/B)))/(DGAMMA(R)*(B**R))
      XS = XU
  102 XU = XU+XI
      WRITE(6,500)
  500 FORMAT('1',T10,'SOLUTION TO THE GAMMA DISTRIBUTION'//
     1T10,'X',T30,'1Y')
      DO 501 J=1,N
```

```
      JA = J*5
  501 WRITE(6,502) JA,Z(J)
  502 FORMAT('0',10X,I3,7X,1PD18.7)
      STOP
      END
```

INTEGRATION SUBROUTINE

```
C  EXTENDED FIVE-POINT GAUSSIAN QUADRATURE
C  EXACT FOR NINTH-DEGREE POLYNOMIAL
C  A = LOWER LIMIT OF INTEGRATION (DOUBLE PRECISION)
C  B = UPPER LIMIT OF INTEGRATION (DOUBLE PRECISION)
C NS = NUMBER OF SEGMENTS
C  ... EACH SEGMENT IS INTEGRATED BY 5-POINT GAUSSIAN
      QUADRATURE
      REAL FUNCTION DGNTGR*8(A,B,NS,FN)
      IMPLICIT REAL *8(A-H,O-Z)
      S = 0.0D0
      D = (B-A)/FLOAT(NS+NS)
      D1 = D*0.538469310D0
      D2 = D*0.906179846D0
      DO 1 J=1,NS
      X=A+D*FLOAT(J+J-1)
    1 S=0.118463443D0*(FN(X-D2)+FN(X+D2))+0.239314335D0*
     1(FN(X-D1)+FN(X+D1)+0.284444444D0*FN(X)+S
      DGNTGR=(B-A)*S/FLOAT(NS)
      RETURN
      END
```

LINKAGE SUBROUTINE

```
      REAL FUNCTION COMXP*8(X)
      IMPLICIT REAL *8(A1H,O-Z)
      COMMON R,B
      COMXP = (X**(R-1.0))*(DEXP(-(X/B)))/(DGAMMA(R)*(B**R))
      RETURN
      END
```

TREND SURFACE ANALYSIS PROGRAM

```
      DIMENSION FMT(20),X(2500),Y(500),XT(2500),M(10),L(10),
     1XTX(100)
      DIMENSION XTY(10),B(10),PY(500),R(500)
      DOUBLE PRECISION X,Y,XT,XTX,XTY,B,R,RSS,CT,SS,CSS,D,PY
C
C  NPRO = NUMBER OF PROBLEM
C
      READ(5,334) NPRO
  334 FORMAT(I5)
      DO 333 JKZ = 1,NPRO
C
C  NC = NUMBER OF CARDS
C
      READ(5,1)NC
    1 FORMAT(I5)
C
C  VARIABLE FORMAT (FMT)
C
      READ(5,2)FMT
    2 FORMAT(20A4)
      CT = 0.0
      SS = 0.0
      IQ = 0
      IA = NC
      IB = IA+NC
      IC = IB+NC
      ID = IC+NC
      IE = ID+NC
      IF = IE+NC
      IG = IF+NC
      IH = IG+NC
      II = IH+NC
      WRITE(6,3)
    3 FORMAT('1','ORIGINAL DATA MATRIX')
      DO 4 J=1,NC
C  DATA CARD = Y,U AND V
      READ(5,FMT) Y(J),X(IA+J),X(IB+J)
      X(J) = 1.0
      SS = SS+(Y(J)**2)
      CT = CT+Y(J)
    4 WRITE(6,989) Y(J),X(J),X(IA+J),X(IB+J)
  989 FORMAT('0',4(F10.4,5X))
      CT = (CT**2)/NC
      CSS = SS-CT
      WRITE(6,999)SS,CT,CSS
  999 FORMAT('-','UNCORRECTED SUM OF SQUARES =',1PD18.7//1X,
     1CORRECTION TERM=',1PD18.7//1X,'CORRECTED SUM OF SQUARES=
     2',1PD18.7)
```

```
      NCOL = 3
105   IQ = IQ + 1
      CALL GMTRA(X,XT,NC,NCOL)
      CALL GMPRD(XT,X,XTX,NCOL,NC,NCOL)
      WRITE(6,500)
500   FORMAT('-','XTX MATRIX')
      NOL = NCOL*NCOL
      DO 501 J = 1,NCOL
501   WRITE(6,502) (XTX(K),K=J,NOL,NCOL)
502   FORMAT('0',10(1PD13.5))
      CALL MINV(XTX,NCOL,D,M,L)
      IF(D.EQ.0.0) GO TO 40
      WRITE(6,503)
503   FORMAT('-','INVERSE CF XTX')
      DO 504 J = 1,NCOL
504   WRITE(6,505) (XTX(K),K=J,NOL,NCOL)
505   FORMAT('0',10(1PD13.5))
      CALL GMPRD(XT,Y,XTY,NCOL,NC,1)
      WRITE(6,506)
506   FORMAT('-','XTY MATRIX')
      DO 510 J=1,NCOL
      WRITE(6,511) B(J)
511   FORMAT('0',1PD18.7)
510   WRITE(7,335) JKZ,IQ,B(J)
335   FORMAT(I3,2X,I3,2X,E20.7)
      WRITE(6,512)
512   FORMAT('1','PREDICTED Y AND RESIDUALS')
      RSS = 0.0
      CALL GMPRD(X,B,PY,NC,NCOL,1)
      DO 995 J=1,NC
      R(J) = Y(J)-PY(J)
      RSS = RSS+(R(J)**2)
995   WRITE(6,993) J,Y(J),PY(J),R(J)
993   FORMAT('-',I5,5X,3(F10.4,5X))
      WRITE(6,513) RSS
513   FORMAT('0','DEVIATIONS',10X,1PD18.7)
      GO TO (18,19,333),IQ
 18   WRITE(6,514)
514   FORMAT('1','QUADRATIC DATA MATRIX')
C
C     FORMATION OF QUADRATIC DATA MATRIX
C
      DO 975 J=1,NC
      X(IC+J) = X(IA+J)**2
      X(ID+J) = X(IA+J)*X(IB+J)
      X(IE+J) = X(IB+J)**2
975   WRITE(6,972) X(IC+J),X(ID+J),X(IE+J)
972   FORMAT('0',3(1PD13.5))
      NCOL = 6
      GO TO 105
```

```
 19   WRITE(6,971)
 971  FORMAT('1','CUBIC DATA MATRIX')
  C
  C   FORMATION OF CUBIC DATA MATRIX
  C
      DO 794 J=1,NC
      X(IF+J)=X(IA+J)**3
      X(IG+J)=X(IC+J)*X(IB+J)
      X(IH+J)=X(IA+J)*X(IE+J)
      X(II+J)=X(IB+J)**3
 794  WRITE(6,970) X(IF+J),X(IG+J),X(IH+J),(II+J)
 970  FORMAT('0',4(1PD13.5))
      NCOL = 10
      GO TO 105
 333  CONTINUE
      GO TO 1000
  40  WRITE(6,515)
 515  FORMAT('1','DETERMINANT = 0.0')
1000  WRITE(6,400)
 400  FORMAT('-','A** END OF RUN ***')
1000  STOP
      END
      GMTRA -MATRIX TRANSPOSE
      GMPRD -MATRIX PRODUCT
      MINV  -MATRIX INVERSION
      OBTAIN FROM 'IBM FORTRAN SCIENTIFIC SUBROUTINE PACKAGE'
```

Nested Analysis of Variance, Ten Levels, and Unequal cases

```
      INTEGER *2 FMT(37)
      REAL MS(10),M(250,10)
      DIMENSION X(1000),L(1000,10),JOE(10),JONES(3),NAME(10),
      N(1000),
     1Y(1000),SSS(10),CM(10,10),DF(10),S(10),JA(10)  ,SOV(9,10),
      ISUM(10)
      DIMENSION Z(250,10),XZ(250,10),VAR(250,10),STD(250,10),
      CV(250,10)
      DATA SOV/90*' '/
  508 KOUNT = 0
      DO 775 J=1,7
  775 JOE(J) = 0
   16 READ(5,1) JONES
    1 FORMAT(3A4)
      CALL REREAD
      CALL ACOMP(JONES,1,'PARAMETER',1,9,KEY)
      GO TO (2,3,2,100),KEY
    2 CALL ACOMP(JONES,1,'FORMAT',1,6,KEY)
      GO TO (4,5,4,100),KEY
    4 CALL ACOMP(JONES,1,'LEVELS',1,6,KEY)
      GO TO (6,7,6,100),KEY
    6 CALL ACOMP(JONES, 1,'SOURCE',1,6,KEY)
      GO TO (8,9,8,100),KEY
    8 CALL ACOMP(JONES,1,'TRANS',1,5,KEY)
      GO TO (10,11,10,100),KEY
   10 CALL ACOMP(JONES,1,'TRANSFER',1,8,KEY)
      GO TO (12,13,12,100),KEY
   12 CALL ACOMP(JONES,1,'END',1,3,KEY)
      GO TO (100,14,100,100),KEY
    3 READ(5,15) NAME,NL
   15 FORMAT(10X,10A4,12)
      IF(NL.EQ.0) GO TO 1010
      IF(NL.LE.2) GO TO 1012
      JOE(1) = 1
      GO TO 16
    5 READ(5,17) FMT
   17 FORMAT(6X,37A2)
      JOE(2) = 1
      GO TO 16
    7 READ(5,1035) (JA(J),J=1,NL)
 1035 FORMAT(10X,10I5)
      DO 1000 J=1,NL
      READ(5,1) JONES
      CALL REREAD
      CALL ACOMP(JONES,1,'C',1,1,KEY)
      go to 9780,781,780,780),KEY
  781 READ(5,782) IC
  782 FORMAT(10X,I5)
```

```
      IJK = JA(J)
      DO 783 K = 1,IJK
785   L(K,J) = IC
      GO TO 1000
780   IJK = JA(J)
      IF(IJK.GT.16) GO TO 980
      READ(5,784) (L(K,J),K=1,IJK)
784   FORMAT(16I5)
      GO TO 1000
980   READ(5,784) (L(K,J),K=17,IJK)
982   FORMAT(12(16I5/))
1000  CONTINUE
      DO 787 J=1,10
787   ISUM(J) = 0
      DO 785 J = 1,NL
      IJK = JA(J)
      DO 786 K=1,IJK
786   ISUM(J) = ISUM(J) + L(K,J)
      IF(ISUM(J).NE.JA(1)) GO TO 788
785   CONTINUE
      JOE(3) = 1
      GO TO 16
9     JOE(4) = 1
      IJK = NL-1
      DO 789 J = 1,IJK
789   READ(5,18) (SOV(J,K),K=1,10)
18    FORMAT(10X,10A4)
      GO TO 16
11    READ(5,999) CONST
999   FORMAT(10X,F5.0)
      JOE(5) = 1
      GO TO 16
13    JOE(6) = 1
      GO TO 19
14    JOE(7) = 1
      GO TO 19
C
C     READ DATA CARDS
C
100   KOUNT = KOUNT + 1
      IF(KOUNT.EQ.1) GO TO 20
101   READ(5,FMT) X(KOUNT)
      READ(5,1) JONES
      CALL REREAD
      GO TO 10
19    IF(JA(1).NE.KOUNT) GO TO 510
      IF(JOE(5).EQ.0) GO TO 21
      DO 22 J = 1,KOUNT
```

```
      IF(X(J).EQ.0.0) X(J) = CONST
   22 X(J) = ALOG10(X(J))
C
C  CALCULATIONS OF SUM OF SQUARES
C
   21 IB = NL
      DO 650 JZ = 1,NL
      CALL NSET(IB,X,L,Y,N,JA,Z,XZ)
      CALL SQUARE(Y,N,IB,JA,SS)
      SSS(IB) = SS
  650 IB=NL - JZ
C
C  CALCULATIONS OF DEGREES OF FREEDOM% SUM SQUARES% MEAN SQUARE
C
      IJK = NL -1
      DO 790 J=1,IJK
      K = J+1
      DF(J) = JA(J)-JA(K)
      S(J) = SSS(J)-SSS(K)
  790 MS(J) = S(J)/DF(J)
C
C  PRINT ANALYSIS OF VARIANCE TABLE
C
      WRITE(6,1055)
 1055 FORMAT('0','        ')
  791 WRITE(6,793) NAME
  793 FORMAT('1',T51,'ANALYSIS OF VARIANCE TABLE FOR'//T25,
      10A4)
      WRITE(6,794)
  794 FORMAT('0',T11,'SOURCE OF VARIATION',T41,'DEGREES OF
      FREEDOM',T77
     1SUM OF SQUARES',T110,'MEAN SQUARE')
      IJK = NL -1
      DO 795 J = 1,IJK
      K = NL - J
  795 WRITE(6,796) (SOV(J,KA),KA=1,10),DF(K),S(K),MS(K)
  796 FORMAT('0',10A4,T48,F6.0,T71,F20.5,T95,F20.5)
C
C  CALCULATION OF COMPONENTS OF VARIANCE
C
      KA = 1
      DO 797 J = 1,NL
      CM(J,J) = JA(1)
  797 CM(J,KA) = JA(J)
      KB = 2
      DO 798 I=3,NL
      DO 799 J = 2,KB
      CALL COMPE(I,J,JA,L,SCM)
      CM(I,J) = SCM
  799 CONTINUE
```

```
798  KB=KB+1
     IJK = NL-1
     DO 800 J=1,IJK
     DO 800 K=1,J
     CM(J,K) = CM(J,K)-CM(J+1,K)
800  CM(J,K) = CM(J,K)/DF(J)
     WRITE(6,801) NAME
801  FORMAT('1',T51,'TABLE OF ESTIMATED COMPONENTS OF
    1VARIANCE FOR'//T2 15,10A4)
     IJK = NL-1
     DO 802 J = 1,IJK
     KZ = NL -J
802  WRITE(6,803) (SOV(J,K),K=1,10),(CM(KZ,K),K=1,KZ)
803  FORMAT('0',10A4,T41,9(F8.4,1X))
C  CALCULATION OF GROUP SUMMARY STATISTICS
C  XZ = SUM(X), Z=SUM(X**2)
C
     BBB = 1000000.0
     DO 632 J=2,NL
     IJK = JA(J)
     DO 632 K=1,IJK
     M(K,J) = XZ(K,J)/L(K,J)
     IF(L(K,J).EQ.1) GO TO 633
     VAR(K,J) = (Z(K,J)-((XZ(K,J)**2)/L(K,J)))
     STD(K,J) = SQRT(VAR(K,J)/(L(K,J)-1))
     CV(K,J) = (STD(K,J)/M(K,J))*100.0
     GO TO 632
633  VAR(K,J)=BBB
     STD(K,J)=BBB
     CV(K,J)=BBB
632  CONTINUE
634  WRITE(6,635) NAME
635  FORMAT('1',T25,'TABLE OF MEANS, VARIANCES, STANDARD
    1DEVIATIONS, AND COEFFICIENT OF VARIATIONS FOR'//T25,10A4)
     WRITE(6,685)
685  FORMAT('0','********** INDICATES NUMBER OF CASES EQUALS
    1ONE')
     DO 636 J=2,NL
     KB = 1
     KA = 0
     JOE(10) = 0
     WRITE(6,637) J
637  FORMAT('0',T51,'STATISTICAL SUMMARY FOR GROUPS IN LEVEL',
    1I10)
646  KA = KA+10
     IF(JA(J).LT.KA) GO TO 638
647  DO 639 K = KB,KA
639  N(K) = K
     WRITE(6,640) (N(K),K=KB,KA)
```

```
 640  FORMAT('0','GROUP',10(9X,I3))
      WRITE(6,1037) (L(K,J),K=KB,KA)
1037  FORMAT('0','CASES',T9,10(2X,I6,4X))
      WRITE(6,641) (M(K,J),K=KB,KA)
 641  FORMAT(' ','MEAN',T9,10(2X,F10.3))
      WRITE(6,642) (VAR(K,J),K=KB,KA)
 642  FORMAT(' ','VAR',T9,10(2X,F10.3)
      WRITE(6,643) (STD(K,J),K=KB,KA)
 643  FORMAT(' ','STD',T9,10(2X,F10.3))
      WRITE(6,644) (CV(K,J),K=KB,KA)
 644  FORMAT(' ','CV',T9,10(2X,F10.3))
      WRITE(6,645)
 645  FORMAT('-')
      IF(JOE(10).EQ.1) GO TO 636
      KB = KB + 10
      GO TO 646
 638  KA = JA(J)
      JOE(10) = 1
      GO TO 647
 636  CONTINUE
C
C  CALCULATION OF LEVEL MEANS
C
      WRITE(6,680) NAME
 680  FORMAT('1',T50,'LEVEL MEANS FOR',5X,10A4)
      DO 681 J=2,NL
      Y(J) = 0.0
      IJK = JA(J)
      DO 682 K=1,IJK
 682  Y(J) = Y(J) + M(K,J)
      Y(J) = Y(J)/JA(J)
 681  WRITE(6,683) J,Y(J)
 683  FORMAT('0',T50,'MEAN FOR LEVEL',I10,'=',G10.3)
      GO TO 956
C
C  ERROR ROUTINE
C
  20  IF(JOE(1).NE.1) GO TO 500
      IF(JOE(2).NE.1) GO TO 502
      IF(JOE(3).NE.1) GO TO 504
      GO TO 101
 500  WRITE(6,501) NAME
 501  FORMAT('1','PARAMETER CARD IS MISSING FOR PROBLEM',5X,
     110A4)
      GO TO 506
1010  WRITE(6,1011) NAME
1011  FORMAT('1','ERROR ON PARAMETER CARD FOR PROBLEM",5X,
     110A4)'NO. OF LEVELS = 0')
      GO TO 506
```

```
 1012  WRITE(6,1013) NAME
 1013  FORMAT('1','ERROR ***** NUMBER OF LEVELS MUST BE 3 OR
      1GREATER FOR PROBLEM',3X,10A4)
       GO TO 506
  502  WRITE(6,503) NAME
  503  FORMAT('1','FORMAT CARD IS MISSING FOR PROBLEM',5X,10A4)
       GO TO 506
  504  WRITE(6,505) NAME
  505  FORMAT('1','LEVELS CARD IS MISSING FOR PROBLEM',5X,10A4)
C
C  SEARCH FOR TRANSFER OR END CARD
C
  506  READ(5,1) JONES
       CALL ACOMP(JONES,1,'TRANSFER',1,8,KEY)
       GO TO (507,508,507,507),KEY
  507  CALL ACOMP(JONES,1,'END',1,3,KEY)
       GO TO (506,509,506,506),KEY
  510  WRITE(6,511) NAME
  511  FORMAT('1','NUMBER OF CARDS READ DO NOT EQUAL TOTAL
      1NUMBER OF CASES IN LEVEL 1',5X,10A4)
  956  IF(JOE(6).EQ.1) GO TO 508
       IF(JOE(7).EQ.1) GO TO 509
       GO TO 506
  788  WRITE(6,957) J,NAME
  957  FORMAT('1','TOTAL CASES OF LEVEL',T5,'DO NOT EQUAL TOTAL
      1CASES OF LEVEL 1',5X,10A4)
       GO TO 956
  509  WRITE(6,1005)
 1005  FORMAT('0','***** END OF RUN ***** PROGRAMMER -
      1SCHROTH *****')
       STOP
       END

       SUBROUTINE NSFT(IB,X,L,Y,N,JA,Z,ZX)
       DIMENSION Z(250,10),XZ(250,10)
       DIMENSION X(1000),Y(1000),N(1000),L(1000,10),JA(10)
       IM = IB
       IJK = JA(IM)
       DO 10 J=1,IJK
       Y(J) = 0.0
   10  Z(J,IM) = 0.0
       I = L(1,IM)
       NA = 1
       DO 1 J=1,IJK
       DO 2 K=NA,I
       Y(J) = Y(J) + X(K)
    2  Z(J,IM) = Z(J,IM) + (X(K)**2)
       NA = 1+I
       XZ(J,IM) = Y(J)
    1  I = I+L(J+1,IM)
       DO 3 J=1,IJK
    3  N(J) = L(J,IM)
       RETURN
       END
```

```
      SUBROUTINE SQUARE(Y,N,IB,JA,SS)
      DIMENSION Y(1000),N(1000),JA(10)
      SS = 0.0
      IJK = JA(IB)
      DO 1 J=1,IJK
    1 SS = SS + ((Y(J)**2)/N(J))
      RETURN
      END

      SUBROUTINE COMPE(I,J,JA,L,SCM)
      DIMENSION JA(10),L(1000,10)
      SUM = 0.0
      SM = 0.0
      KA = 1
      SCM = 0.0
      IJK = JA(J)
      DO 1 JY = 1,IJK
      SUM = SUM + L(JY,J)
      IF (SUM.EQ.L(KA,I) GO TO 2
      SM = SM + (L(JY,J)**2)
      GO TO 1
    2 SM = SM + (L(JY,J)**2)
      SM = SM/L(KA,I)
      SCM = SCM + SM
      SUM = 0.0
      SM = 0.0
      KA = KA +1
    1 CONTINUE
      RETURN
      END

   SUBROUTINE ACOMP(CH1,NCH1,CH2,NCH2,N,K)
C NO WRITEUP TO BE PUT OUT.
C ONLY FOR EASE IN CONVERTING 7074 LIBRARY PROGRAMS.
C USES CHCOMP SUBROUTINE TO COMPARE THE N CONTIGUOUS CHARACTERS
C START IN AT CHI(NCH1) WITH THE CHARACTERS STARTING AT CH2(NCH2).
C K IS SET EQUAL TO 1,2, OR 3 IF A CHARACTER OF CH1 PRECEEDS THE
C CORRESPONDING CHARACTER OF CH2, ALL N CHARACTERS OF THE TWO
C STRINGS ARE THE SAME, OF IF A CHARACTER OF CH2 FOLLOWS THE
C CORRESPONDING CHARACTER OF CH2, RESPECTIVELY, IN THE COLLATING
C SEQUENCE.
C

      INTEGER*2 CH1(1),CH2(1)
      CALL CHCOMP(CH1(NCH1),CH2(NCH2),N,&1,&2,&3)
    1 K=1
      RETURN
    2 K=2
      RETURN
    3 K=3
      RETURN
      END
```

ASSEMBLER SUBROUTINES

SUBROUTINE	FUNCTION
REREAD	TO REREAD A CARD
CHCOMP	TO COMPARE STRINGS OF CHARACTERS

APPENDIX III

B Coefficients for the Cubic Trend Surfaces

	Percent Organic Carbon	Percent Total Nitrogen	Cation Exchange Capacity
b_0	-30.7886	-3.2312	-17.1583
b_1	10.1575	1.4425	13.2500
b_2	8.5882	0.7158	16.3918
b_3	-0.7840	-0.1712	-0.7037
b_4	-0.1418	-0.1099	-2.2375
b_5	-0.4583	-0.0390	-1.0606
b_6	-0.0112	0.0044	-0.0629
b_7	0.0649	0.0073	0.1581
b_8	0.0185	0.0015	0.0317
b_9	0.0080	0.0007	0.0213

B Coefficients for the Cubic Trend Surfaces

	Percent Base Saturation	Total Bases (meq/100g)	Exchangeable Calcium (meq/100g)	Exchangeable Magnesium (meq/100g)
b_0	-30.3746	-2.2059	1.5900	-0.7071
b_1	51.8688	10.2911	5.1842	3.3686
b_2	14.9761	9.6470	6.1045	2.9163
b_3	-8.2641	-0.5879	0.0212	-0.4192
b_4	-5.7562	-2.7295	-1.7452	-0.7920
b_5	-0.7786	-0.5724	-0.3750	-0.1700
b_6	0.4765	-0.0140	-0.0307	0.0125
b_7	0.4858	-0.2163	0.1332	0.0673
b_8	0.0354	0.0222	0.0139	0.0070
b_9	0.0229	0.1451	0.0098	0.0040