# CATION EXCHANGE OF SOME ETHIOPIAN SOILS

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# INTRODUCTION

It is recognized that any soil is the product of the interactions of parent material, biosphere, atmosphere, topography, and time (22).[1] Accordingly, the soils of Ethiopia are formed for the most part by the combined actions of tropical and subtropical climates on basaltic rocks and volcanic tuffs found on a strongly rolling topography. In some areas sedimentary and metamorphic rocks are also known to occur. The country is primarily agricultural, over eighty-five percent of its population being employed in this profession.

Certain writers in the past have commented that the soils are generally fertile and have inferred that they are potentially productive. However, most of the conclusions drawn pertaining to these soils were based on casual observations, and detailed data have been scarce. Shantz and Marbut (41) jointly reported in 1923 that the soils over considerable areas are derived from basalt and other dark-colored igneous rocks. They maintained that these parent materials gave rise to a very fertile young soil which is renewed "as the soil is rejuvenated." That the sedentary soils of this country are the result of lateritic soil forming process is also mentioned in Guide Book of Ethiopia (2), and that these soils are generally neutral to acid in reaction and have ample quantity of available phosphate and potash was reported in 1954 (45). Murphy (34) made laboratory analyses of several samples of representative soils of Ethiopia. His investigations covered the current status of soil fertility in relation to organic matter, total

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[1] Numbers in parenthesis refer to literature cited.

nitrogen, and available phosphorus, potassium, calcium, and magnesium. In addition, he made determinations of pH, texture, color, and structure of these soils. His information shows that a large portion of the soils of the agricultural regions of the country consist of lateritic clays, clay loams (latosols), and blackland clays. The latosols fit fairly well into the description made by Kellogg (25), and the blackland clay soils are similar in characteristics to the Regur soils of India described by Simonson (43).

The importance of cation exchange in connection with the fertility and physical properties of the soil cannot be overemphasized. Mehlich and Coleman (30) made the following statements regarding the importance of exchangeable cations in soils: "....we must look upon the exchangeable ions as being the immediate source of cationic plant nutrients in most soils."; "It is well established that there is a rough proportionality between the concentration of a given cation in a plant and that of the nutrient solution in which it is grown."; "In general, soils are potentially more productive when the cation exchange is high than when it is low."; and "The ability of plants to utilize soil exchangeable cations is no longer questioned." In this connection these investigators pointed out that the ability of plants to utilize exchangeable cations was first established by Nostilz in 1925 and confirmed by Joffe and McLean in 1927, by Gedroiz in 1930, and by Jenny and Cowan in 1933. Marshall (28) expressed the opinion that the importance of cation exchange in nature is surpassed only by photosynthesis.

From these statements it becomes clear that it is desirable to have a knowledge of cationic exchange conditions prevailing in soils. What is more, the exchangeable cations in the soil are also pertinent to the construction engineer because of their influence on the physical properties of soils which is reflected by such variations as in the qualities of the highways built on different groups of soils in Ethiopia. However, published information of even an empirical statement regarding cation exchange seems to be unavailable in the country.

This thesis is an attempt to furnish more information on the cation exchange, base saturation, and soil reaction of some blackland, reddish brown, and brown to dark brown soils of Ethiopia.

# REVIEW OF LITERATURE

Before the concept of cation exchange was established, some findings were made by early workers. Prescott (36) reported that Aristotle knew that sea water lost some of its taste by filtration through sand; that Lord Bacon had discussed the question of making sea water potable by filtering through sand; that Le Comte de Marsilli filtered sea water through 15 successive vessels of garden soil with a diminution in salt content; and that Boyle Godfrey in 1737 observed that when sea water was passed through a stone straining cistern the first pint was like pure water and had no salty taste, but the succeeding pint was salty. Prescott further reported that Gazzeri observed that soil and especially clay took up soluble substances which he considered to be advantageous since later on they might become available to plants as needed. He also reported on Liebig's conviction that this process was a physical and not a chemical phenomenon. According to this report, Van Bemmelen first introduced the concept of colloids--both organic and inorganic--into soil problems, and suggested that soil absorption is a chemical and not a physical phenomenon.

Following these early observations and investigations, other workers have clearly established that cation exchange is a chemical phenomenon. Thompson (47) made a systematic study of the subject from 1845 to 1850. By mixing ammonia with soil and leaching the mixture with water, he discovered that part of the amonia was retained by the soil. Way (51) and Thompson (47) independently discovered that when soil was leached with ammonium sulfate, the leachate contained calcium sulfate and not ammonium sulfate. The former observed that the behavior of both potassium and ammonium salts was alike. He argued further that ammonia and potash retention by the soil could be possible only in the form of insoluble salts of these alkalis, and the existence of "similar salt of lime" for interchange occurred. He concluded that the "salt of lime" was associated with the clay and had linkage with the silicate compounds of the soil. His first paper dealing with cation exchange, followed by a number of others afterwards, was published in 1850. Forschamer (12) revealed in 1850 that leaching the soil with sea water released calcium and magnesium.

That the phenomenon of cation exchange resides essentially in organic matter and the clay fraction of the soil has been reported by several investigators (10,39). Russell (30) in his discussion on cation exchange cites the work of R. K. Schofield in measuring the charges carried by clay particles. It was brought out in the discussion that cation holding power of soils is a function of negative charges developed as a result of distinct mechanisms occurring in the soil in the following manner:

(a) There are permanent negative charges on the clay lattice and other minerals due to isomorphous substitution, and the clay minerals hold a "definite" amount of cations to neutralize the charge due to isomorphous substitution.

(b) There are negative charges which develop due to dissociation of hydrogen ions from hydroxyls attached to silicon atoms "at the broken edges of the oxygen sheets" composing the clay mineral. The reaction involving this is written as follows:

$$\equiv \mathrm{Si{-}OH} + H_2O \dashrightarrow \equiv \mathrm{Si{-}O^-} + H_3O^+$$

In a pH range of 6.0 and above, the clay minerals hold adequate bases for the neutralization of the weak acids resulting from the dissociation of the hydrogen ions of certain hydroxyls. As the reaction changes from neutrality to alkalinity, there is a corresponding increase in the magnitude of negative charges.

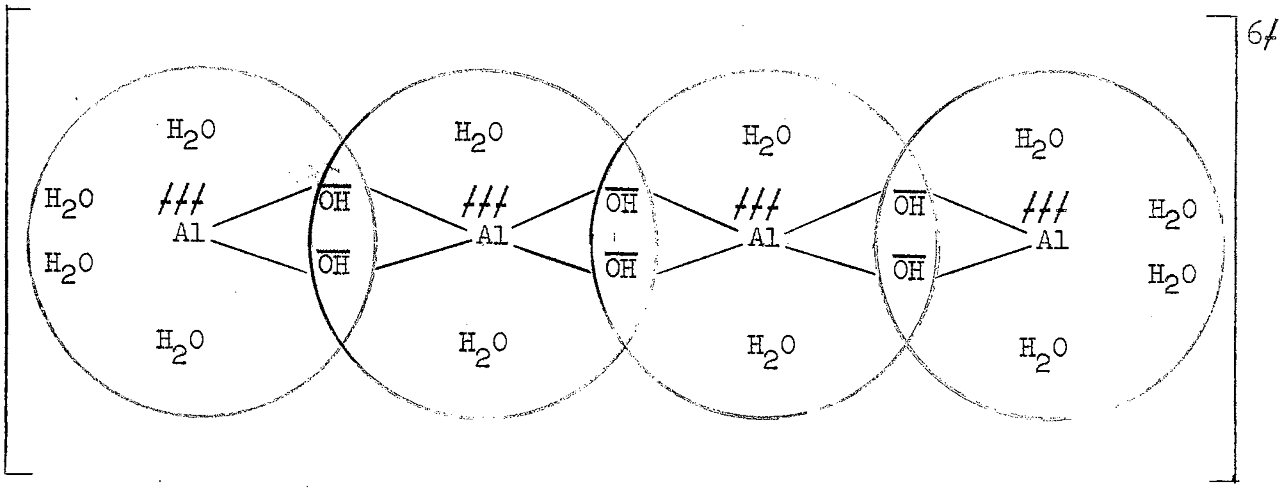
(c) There is a dissociation of hydrogen ions from carboxyl groups of the organic matter in the soil at varying ranges of reaction below pH 6.0.

(d) Hydrogen ions are dissociated above pH 6.0 from hydroxyls linked to organic matter.

(e) Aluminum ions in a form of "trivalent ions in 6-coordination with water under acid conditions" are also responsible for the dissociation of hydrogen ions from the coordinated water molecules as acidity is lessened. Much of the buffering of the soil is accounted for by these reactions. Under a very acidic environment of pH lower than 4.0, single aluminum ions are present with three positive charges developed by six water molecules in 6-coordination, and the addition of base to the medium gives a boost to the hydroxyl ions. This requires the dissociation of hydrogen ions from "one or two of the water molecules surrounding the aluminum" in order to neutralize the added hydroxyls. Consequently, one or two hydroxyl ions are left around the aluminum. The resultant unit is unstable and thus links itself to a similar unit by sharing two hydroxyls and losing two water molecules. Following this, there are four positive charges left for the unit instead of six, which permits a fraction of the added basic cations to neutralize some of the permanent negative charge on the clay. The equation below further illustrates this point:

$$2Al(H_2O)_6^{3+} + 2OH^- \dashrightarrow \left[Al_2(OH)_2(H_2O)_8\right]^{4+} + H_2O$$

As the pH increases, more dissociation of hydrogen ions from the coordinated water molecules occurs with resultant units schemed by Russell as follows:



When the pH is 5.0 or above, the units join and precipitate as $Al(OH)_3$ which is stable until the pH climbs to 9, when it breaks up into aluminum ions in 4-coordination with hydroxyls and gives the aluminate anion, $Al(OH)_4$.

Grim (16) asserted that the broken bonds are the origin of the unsatisfied charges. Further, he pinpoints the specific areas of the occurrence of the phenomenon; viz.--it happens around the edges of the silica-alumina units, on vertical planes, parallel to the c-axis of the sepiolite-palygorskite-attapulgite minerals. These broken bonds are known to account for much of the exchange capacity in kaolinite and halloysite minerals. The exchange capacity increases with an increasing magnitude of broken bonds due to lattice distortions, decrease in size of particles, and increase of degree of crystallinity. Grim also showed that within the lattice structure substitutions of trivalent aluminum for quadrivalent silicon in the tetrahedral sheet and magnesium for trivalent aluminum in the octahedral sheet take place in the development of the unbalanced charges of some clay mineral structural units. In montmorillonites and vermiculites, 80 percent of the total cation exchange capacity is due to isomorphous substitution. The other 20 percent is due to broken bonds. For illite and kaolinite, the cations are largely at the edges. When cation exchange results from broken bonds, the exchangeable cations are held around the edges of the flakes and elongated units. Where lattice substitution is the case, the cations are, for the most part, on the basal plane surfaces.

The following table, adapted from Grim, shows the exchange capacities of different clay minerals at pH 7.0:

| Clay Mineral | m.e./100 gm. |
|---|---|
| Montmorillonite | 80-150 |
| Kaolinite | 3- 15 |
| Illite | 10- 40 |
| Vermiculite | 100-150 |
| Halloysite $2H_2O$ | 5- 10 |
| Halloysite $4H_2O$ | 4- 50 |
| Chlorite | 10- 40 |
| Sepiolite-attapulgite-palygorskite | 20- 30 |

According to Grim (16), the exchange reaction is slowed down upon the heating of the clay in which case the cations tend to become a part of the lattice structure, followed by a lowering of the swelling property. The exchange capacity of montmorillonite is reduced by the presence of aluminum on exchange positions, apparently because it ruptures the lattice and clogs the exchange positions. Similar effects are caused by $Fe_2O_3$, organic ions, and sulfur compounds. An increase in concentration of replacing cations increases the exchange as cation exchange is a "stoichiometric reaction" and is governed by the law of mass action. Kelley and Jenny (24) showed that cation exchange capacity is increased by grinding. Millar (32) stated that cations vary in their replacing ability, the difference being determined by the degree of hydration, migration velocity, and charge carried by the ion. In general, the lesser the hydration, the more effective the replacing power. Also, the greater the charge, the more efficient the replacing ability; that is to say, bivalent ions will replace monovalent ions, and trivalent ions will replace bivalent ions. The hydrogen ion, however, is most effective in replacement of those ions commonly present in quantity, but cannot replace $Al^{+++}$ or $Fe^{+++}$. The replacing power in descending order appears to be: $H^{+}$, $Ca^{++}$, $Mg^{++}$, $K^{+}$, $Na^{+}$, according to Kelley (23).

Organic matter has been shown to have significant exchange capacity, and has, therefore, received special treatment by soil scientists. Grouley and Wander (17) and Sturgis and Moore (46) confirmed that organic matter exerts a depressive effect on potassium fixation, because organic matter is in direct competition with the mineral or inorganic fraction of the soil for exchangeable cations. Marshall (29) suggested that organic matter contributes calcium to the soil solution in two ways; namely, (a) by holding exchangeable calcium, and (b) by releasing the calcium retained upon decomposition. Broadbent (6) stated that organic matter is negatively charged, and as such, it attracts positively charged ions. He also mentions that the retentive capacity of the organic matter is greater than that of the most reactive clays. The two ways whereby cations are retained, according to Broadbent, include: (a) those which occur by the formation of salts of the carboxylic acids, and (b) those which involve the forming of the molecular ring structures, in which case the nutrient cation happens to be part of a ring to form a metal organic complex. The same authority reported that inasmuch as the presence of organic matter lowers the tendency of the soil pH to change when acid or alkaline materials are added, acid soils with high organic matter content require more lime to "bring them to neutrality" than soils of low organic matter content.

The "ease of exchange" of isomorphically substituted ions in the crystal lattice of clay minerals was discussed by Russell (39). He pointed out that the structure of clay minerals is dominated by oxygen layers, and since it takes a particular sized metallic ion to fit into the interstices of these layers, only few find their way into the lattice. Firstly, isomorphous substitution is limited for the most part to the time prior to the formation of the lattice. According to Russell, the radius of the largest ion that can just fit into the tetrahedral space between the four contiguous oxygens is 0.225 times the radius of the oxygen ion, and into the octahedral space between six oxygens is 0.414 times the oxygen radius. If the ions are larger than the holes they are to fit, distortion of the lattice takes place and stability is lost. Silicon and aluminum being of relative small sizes are the only ones capable of fitting the interstices of the lattice without distortion. Jenny and Reitemeier (21) reported that the replacing power of ions increases with the increasing size of the ions of the same valence.

The degree of saturation of the different ions has a significant role in influencing the fertility status of various soils and plant growth. According to Allaway (1), the replaceability of the replaceable calcium was increased by increase in percentage in calcium saturation from all of several colloids studied. Gedroiz (14) found that when the exchange capacity of a soil was saturated with any one of the following bases: H, $NH_4$, Na, K, Mg, Ca, Sr, Cd, Ba, Mn, $Fe^{++}$, Co, Ni, Cu, Al, and $Fe^{+++}$, only in the chernozem soil saturated with calcium was the yield of oats as large as that produced on the original soil. When there was practically a complete removal of exchangeable calcium from the soil, the plant was unable to use nonexchangeable calcium, and calcium fertilization was necessary. Peech and Bradfield (35) state that in the absence of free calcium carbonate and water soluble salts, exchangeable calcium constitutes the immediate supply of the available as well as a large proportion of the total reserve supply of calcium, especially in fine-textured soils. Thorne (48) found that the yield of tomato plants decreased when the level of exchangeable sodium was above 40 percent of the exchange capacity of the clay. Plant growth continued with a potassium saturation of 90 percent of the exchange capacity, although the yield decreased when the potassium saturation of the exchange capacity was above 60 percent. The highest level of tolerance was between 60 and 70 percent of the total exchange capacity.

Chu and Turk (8) secured a nearly linear relationship between growth of plants and degree of base saturation of montmorillonitic media, while with kaolinitic media increases in yield were not significant above 40 percent total base saturation. Exchangeable calcium and potassium held by illitic colloids appeared to be less available than those held by montmorillonitic colloids at the same degree of saturation. From a practical viewpoint, this means that montmorillonitic and illitic soils must be kept at a high level of calcium saturation in order that plants growing on them may secure their necessary calcium. Their results indicate that neutralizing an acid soil with calcium or magnesium should make the exchangeable potassium more available. Marshall (29) indicated that exchange cations of kaolinite are more extensively ionized than those of montmorillonite clays, which tends to compensate to some extent for the lower cation exchange capacity of kaolinitic soils. He states: "Below 70 percent saturation with calcium montmorillonite clays are characterized by an extremely low active fraction and hence by a high energy of absorption for the calcium ions." This means that the calcium saturation of montmorillonitic clays must be above 70 percent in order to better the root environment for calcium. In the case of kaolinitic clays, Marshall showed that there was no zone where calcium is so tightly held. This means that liming should extend the degree of calcium saturation of montmorillonitic clays above 70 percent saturation in order to have an appreciable effect on the supply of calcium for the plant, while any liming of an acid kaolinitic clay should be beneficial in supplying the plant with needed calcium. Kelley (23) reported that the activity of a given kind of exchangeable cation diminishes as the percentage saturation of that cation decreases, and with calcium the availability diminishes rapidly with the lowering of calcium saturation. Even with 40 to 50 percent calcium saturation, the **plants** may have difficulty getting calcium, while they are able to secure their potassium needs from exchange material having a low potassium saturation. Harper (18) stated that the amount of calcium, magnesium, and potassium in a soil available for plant use depends on the base exchange of the soil, and that the quantity of these nutrients gradually declines as acidity increases.

The relationship of pH to base saturation and cation exchange deserves a brief discussion here. First a brief resumé on pH itself is helpful (9). In the soil sometimes the water molecule happens to ionize according to scheme: $H_2O \longleftrightarrow H^+ + OH^-$. The number of water molecules ionized at any one time is as small as one in ten million molecules. The extent of ionization of the water molecule is still clearer when explained in terms of an ionization constant, $Kw = \left[H^+\right] \left[OH^-\right]$. $\left[H^+\right]$ and $\left[OH^-\right]$ stand for the concentrations of hydrogen ions and hydroxyl ions respectively. These concentrations are expressed in terms of equivalents per liter; and "one equivalent of a singly charged ionic species is the weight in grams of that species, which contains $6.023 \times 10^{23}$ particles." Kw is $10^{-14}$ at 22 degrees centigrade which is the product of the concentrations of hydrogen and hydroxyl ions. Expressed in another way, the above equation follows:

$$\log \frac{1}{Kw} = \log \frac{1}{\left[H^+\right]} + \log \frac{1}{\left[OH^-\right]} = 14.00$$

These values of $\log \frac{1}{\left[H^+\right]}$ and $\log \frac{1}{\left[OH^-\right]}$ are called pH and pOH respectively, and they are the indices of the acidity and alkalinity of a system. When pH and pOH are equal, such a system becomes neutral. At 22 degrees centigrade as Kw equals $10^{-14}$, pH = pOH = neutral. When pH is above 7, the system is alkaline, and when it is below 7, the system is acidic. The range of pH in soils varies from 4 to 10, and most agricultural soils have a range of 5 to 8.5. Because of the cation properties, the pH of a soil-water system reflects the approximate hydrogen ion concentration and not the total acidity of the system. The usual way of expressing the cation exchange capacity is in terms of milliequivalents of cations required to neutralize the negative charge of 100 grams of soil at pH 7. Coleman and Mehlich (9) have classified the two known sources of cation exchange capacity as (a) permanent charges, and (b) pH dependent charges.

They state that clay minerals possess permanent charges due to their crystal structure and also pH-dependent charges resulting from the ionization of hydrogen ions from exposed SiOH groups.

The influence of exchangeable cations upon the physical properties of soils has received wide attention by several investigators. Ratner (38) brings to light that sodium causes retardation of capillary rise of water, decreases filterability, and increases dispersability and swelling. This is observed to be more marked in organic matter rich soil than in low organic matter soil. Gill and Reaves (15) reported the close correlation of shrinkage of natural clods in the tillable range of soil moisture with the cation exchange. Brooks et al. (7) showed that a slight increase in permeability ratio with increasing exchangeable magnesium and decreasing exchangeable sodium took place in the eight soils with which they worked. The exchangeable potassium effect paralleled that of magnesium; the former reduced the modulus of rupture. Webb (52) noticed that soil treatment with sodium lowered the index of friability and that the difference between index of friability of a sodium-treated and a calcium-treated soil was greater for wet than for dry soil. Gedroiz (13) was of the opinion that as long as 80 percent or more of the exchangeable bases is calcium, the soil would have a maximum friability.

Cations affect each other in their uptake by plants. Zimmerman (53) concluded from a study of the influences of exchangeable calcium, magnesium, and potassium on plant growth that at higher fertility levels calcium can be harmful unless accompanied by an adequate magnesium supply. Furthermore, magnesium is needed not only for calcium balance but even more so to overcome high amounts of potassium. Hoagland (19) reported that an increase in the amount of absorbable calcium or magnesium may tend to decrease the uptake of potassium from a low potassium medium, but this effect is less than the effect of potassium on the absorption of calcium and magnesium. Mehlich and Reed (31) observed that the addition of calcium sulfate increased leaching losses of applied potassium and magnesium. The losses of these nutrients became less at higher degrees of calcium saturation. They found that the calcium intake of cotton increased with increasing degree of calcium saturation; the magnesium intake increased up to about 40 percent calcium saturation and thereafter remained rather constant; and the potassium intake increased with an increase in potassium level of the soil and with increasing degrees of calcium saturation up to about the 40 percent level. They also found that the magnesium and calcium in the plants decreased with increasing levels of potassium. Jenny and Ayres (20) found that the availability of potassium to plants, particularly at the lower levels of potassium saturation, was greater when calcium was the complementary ion than when hydrogen was the complementary ion. Seatz and Winters (40) showed that much more potassium was released when the complementary ion was largely calcium than when it was dominantly hydrogen.

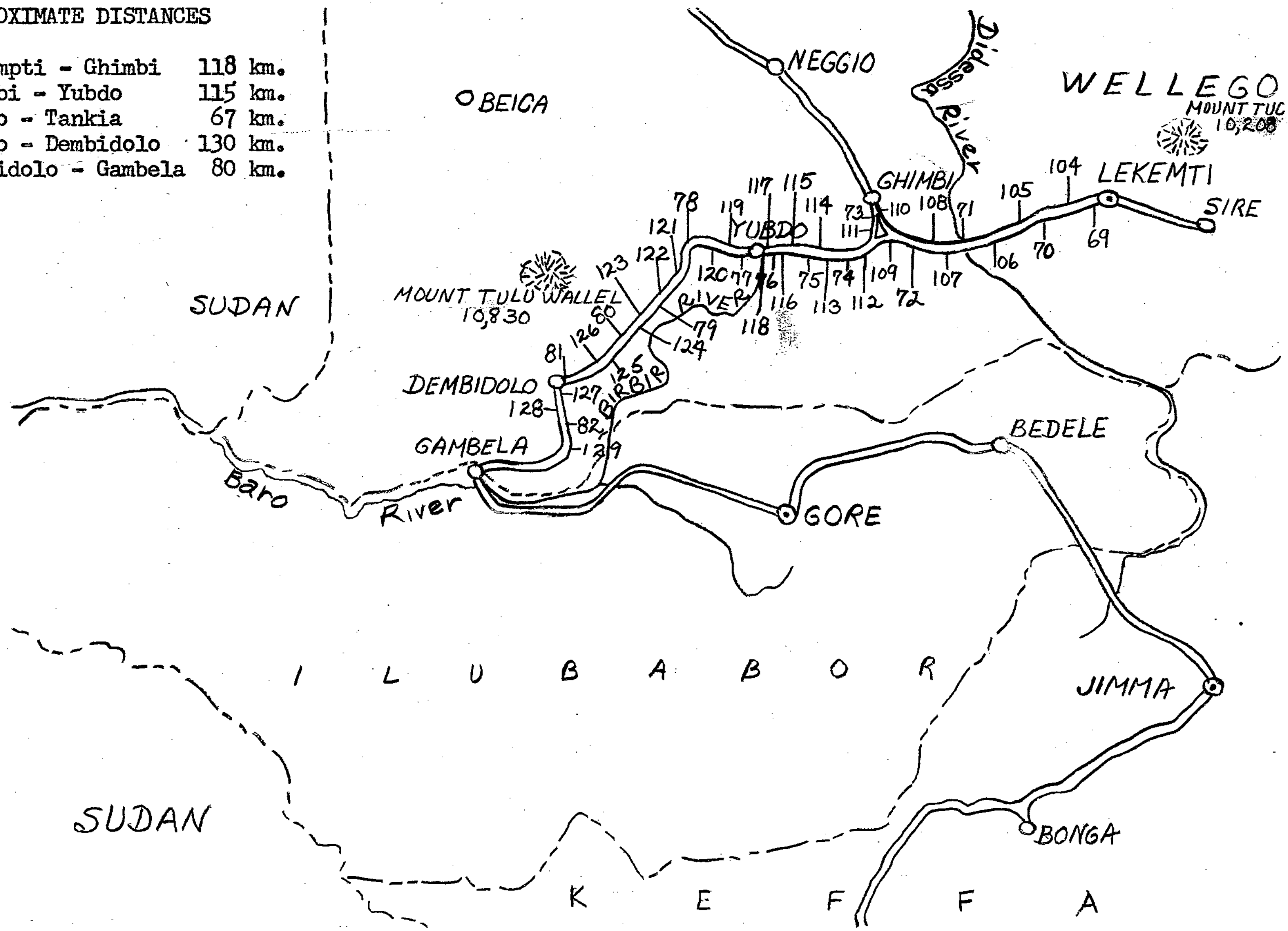
Lunt and Nelson (27) studied the value of sodium in the mineral nutrition of cotton. They found that increasing sodium or potassium increased the hydration of the cotton plant; cotton seed was also increased 25 percent by the addition of sodium when the potassium level was inadequate. Sodium decreased the uptake of potassium. In the tops, seeds, and roots, sodium decreased the calcium and magnesium content. Bower and Turk (5) reported that the deficiency of both calcium and magnesium may exist in alkali soils which have a high sodium content. Lehr (26) indicated that foliage and roots react differently to the proportions of ions in the soil. Sodium is also reported to have a potassium conserving effect. Reports (44, 49, 50) indicating the depressing effect of high concentrations of calcium and potassium on the absorption of magnesium by plants are found in the literature. Potassium appears to have a greater depressing effect than calcium. Bear et al. (4) worked with twenty of the most important agricultural soils of New Jersey. They reported that for alfalfa the exchange complex of the ideal soil should consist of about 65 percent calcium, 20 percent hydrogen, 10 percent magnesium, and 5 percent potassium. They believed that the critical lower limit in the soil's supply of potassium to be at 0.15 to 0.25 milliequivalents per 100 grams of soil.

# MATERIALS AND METHODS

Soil samples collected from various locations in Ethiopia were secured and used in this study. Permission for the entrance of the samples into the United States was granted by the United States Department of Agriculture, Plant Quarantine Division. Figure 1 shows in a general way the areas where the soil samples were collected in western Ethiopia. The locations of the other samples are designated in the tables.

## Description of Soils

Dark (blackland) clay soils (34): The climax vegetation found on these soils appears to consist of short to tall grasses. Under cultivation, the soils grow Erograstis abyssinica and other small grains. They are found on rolling to level topography of good to mediocre surface drainage. Basaltic rocks are predominant; however, in certain localities limestone prevails. The profiles are deep with some exceptions, and the clay content is very high throughout the profile. The swelling and shrinkage properties and the high exchange capacity of these soils suggest that the montmorillonitic clay group is predominant. When wet, the soils are plastic, sticky, and structureless. When dry, they exhibit crumbling, self-mulching, and granular structure; they contract and form wide, deep cracks when very dry. Plant residues and the rather hard granules fall down these cracks and are later enveloped by the horizontal and vertical swelling of the clay as the ground gets wet. Calcium carbonate concretions are to be found on the surface as well



APPROXIMATE DISTANCES

| | |
|---|---|
| Lekempti - Ghimbi | 118 km. |
| Ghimbi - Yubdo | 115 km. |
| Yubdo - Tankia | 67 km. |
| Yubdo - Dembidolo | 130 km. |
| Dembidolo - Gambela | 80 km. |

FIGURE 1. Shows where samples 69 to 82 and 104 to 129 were collected in Western Ethiopia.

as throughout the entire profile in many cases. The range of the soil reaction is from about pH 5.0 to pH 8; however, the soils are very often just slightly acid to slightly alkaline.

The profiles of these blacklands will vary some, but a typical profile in the Ghibai area occurring on a very gentle slope with acacia-tall grass cover shows:

| | | |
|---|---|---|
| 0-12 inches | - | very dark gray clay, granular surface, subangular blocky below |
| 12-42 inches | - | very dark gray to black clay, appearing massive but breaks to subangular blocks |
| 42-60 inches | - | very dark grayish brown to very dark gray clay, some $CaCO_3$ concretions, subangular blocky |

For further details on individual profiles, see Table 3.

Reddish brown soils (34): These soils are found on gentle to steep slopes; however, they are dominant on steep slopes. The structure is moderate to strong, coarse, granular on the surface; it is firm, moderately coarse, subangular blocky in the subsurface where the clay content is higher than at the surface. They have a loamy feel although by mechanical analysis they are usually clay loam or clay. The profiles are usually deep and permeable. These soils absorb water readily, and although they are sticky immediately following a rain, the surface dries rather rapidly to a nice friable structure. The predominating clay minerals are probably kaolinite and some montmorillonite although no data are available to support this statement. The organic matter is usually rather high, ranging from 3 to 8 percent in the plow zone. The pH range is usually from slightly less than 5.0 to about 6.0. Essentially there is no difference in the properties between the reddish brown soils and the brown to dark brown soils except in color.

A profile of a virgin soil near Jimma shows:

0-10 inches - 35 percent sand, 20 percent silt, 45 percent clay; 5 YR 4/4; granular; pH 5.6

10-24 inches - 21 percent sand, 18 percent silt, 61 percent clay; 5 YR 4/6; horizontal cracks; pH 5.7

24-42 inches - 12 percent sand, 8 percent silt, 80 percent clay; 5 YR 4/6; vertical cracks; pH 6.0

60 inches + (undetermined) - 27 percent sand, 14 percent silt, 59 percent clay; concretionary zone; 5 YR 5/6; pH 6.2

The entire profile was dark reddish brown when moist. The organic matter for the respective horizons was 5.20 percent, 2.35 percent, 1.25 percent, and 0.25 percent. In some profiles the acidity may increase slightly with depth. For further details on individual profiles, see Table 6.

## METHODS EMPLOYED

| | |
|---|---|
| Soil color | The soil color was determined by comparison with the Munsell Soil Color Chart. |
| pH | The pH was determined by the use of the Beckman Zeromatic pH-meter from a soil paste. |
| Texture | Soil texture was determined by the Bouyoucos method where the samples of soil were sufficient. Where the samples were too small, the texture was determined by feel. |
| Cation exchange capacity | Cation exchange capacity was determined by the neutral ammonium acetate method. |
| Exchangeable bases | Exchangeable bases were determined on the ammonium acetate leachates using the Beckman Model DU-Flame Spectrophotometer with a photomultiplier attachment. |

## RESULTS AND DISCUSSION

The data presented are factual as secured and calculated from the results of the methods employed. No field data are available in Ethiopia for use in making interpretations. However, in light of interpretations made by investigators from field and laboratory data from other regions, it is thought that the interpretations made from these data on Ethiopian soils merit consideration.

Dark Colored Soils: The pH of these soils varied from as low as 4.9 to nearly 8.0. The more common pH range is about 6.3 to 7.4, which is a desirable range for plant growth. All of these soils have a high cation exchange capacity. The range was 36.17 to 63.67 milliequivalents per 100 grams of soil with an average of 55.05 milliequivalents. It has already been brought out that soils with a high cation exchange capacity are potentially more productive than those with low exchange capacity (30). The total bases extracted with neutral ammonium acetate were high. In some cases the extracted amounts exceeded the exchange capacity. This was due to the presence of soluble basic materials in the soils. These were not removed prior to ammonium acetate treatment; hence, not all of the bases indicated as being removed by the ammonium acetate were in the exchange complex. With the more acid soils (soils with relatively low pH) apparently a considerable amount of the bases was in soluble compounds and was not a part of the exchange complex. Regardless of this, however, the amount of each of the several bases available for plant use appears to be sufficient with perhaps a few exceptions.

From the physical properties as already described and the high cation exchange capacity, montmorillonite is probably the major clay mineral occurring in these soils. As measured by Marshall's figure (29) of 70 percent calcium saturation of montmorillonitic clay as an index for needed calcium, some of these soils might respond to a calcium treatment for plants which have a high calcium requirement. Kelley (23) states that in some cases plants are unable to secure their needed calcium even with a calcium saturation of 40 to 50 percent. A few of these soils would fall into this category. The magnesium content appears to be quite sufficient. According to Bear et al., the ideal soil has a calcium-magnesium ratio of about 6.5. These soils have a range of calcium-magnesium of 0.52 to 4.20 with an average of 2.30. This means that the magnesium is high in respect to the calcium. The potassium is high, ranging from 207 to 1360 ppm with an average of 711 ppm. Only with a lower limit of 60 ppm (4, 33) is response very likely, and with 80 to 100 ppm of potassium, response is doubtful. Murphy (33) shows that there is definitely no response when the exchangeable potassium is as high as 200 ppm. High exchangeable potassium (19, 31) is known to depress the availability of calcium and magnesium. This would be especially the case where the supplies of calcium and magnesium are low. With the soils in question, the magnesium is high and such an effect on its availability is quite questionable. Sodium was not a problem in these soils, except perhaps for a few soils in the Ghibai valley where it appeared in above average amount.

Reddish Brown, Dark Brown, and Brown Soils: As has been previously stated, color is the primary basis for any separation of these soils. However, there are some chemical differences. These differences are in magnitude only, and therefore the major discussion will concern these soils as a group.

There is a sharp contrast between these soils and the dark colored soils as can be readily observed from the tables. Outstanding is the difference in the cation exchange capacities. While the average cation exchange capacity is 55.05 milliequivalents per 100 grams for the dark soils, the average for these soils is 25.00 milliequivalents. Though these soils get sticky when wet, they dry to a friable structure without the development of large cracks. This is in contrast to the nature of the physical properties of the dark soils already described. It is quite apparent that a difference exists in the type of clay present in these two different soil groups. The properties of the dark soils are those generally associated with montmorillonitic clays, while those of this group resemble more closely soils in which kaolinitic type of clays predominate. No identification procedures were conducted to definitely identify the clay minerals present, however, in either of the two groups. In general, these reddish brown to brown soils are higher in organic matter than the dark soils (34). Organic matter may be contributing appreciably to the cation exchange in these soils.

Another major difference between these soils and the dark (blackland) soils is the pH. While the surface soil of the dark soils may vary from perhaps strongly acid to moderately alkaline, the pH increases with depth and is commonly between pH 7 and pH 8 in the lower part of the profile. With the reddish brown soils, the entire profile is acid, although in some cases the lower part of the profile may have a slightly higher pH than the surface. The range in pH of the surface soil is approximately pH 4.7 to pH 6.3. Most of these soils have a pH between 5.0 and 6.0. Rarely is the pH more than about 6.3 at depths of 5 or 6 feet. Thus, these profiles have been rather highly leached while those of the dark soils show leaching effects only in the surface ordinarily--the subsurface and subsoil being calcareous--pH 7.4 to pH 8.0 or slightly more (34).

The base saturation of the reddish brown to brown soils is variable but quite commonly (Table 4) is between 35 percent and 60 percent. The average calcium saturation is 30.95 percent. The reddish brown soils are usually lower in cation exchange capacity, base saturation, exchangeable calcium, magnesium, and potassium than the brown to dark brown soils. As an average for 36 samples of reddish brown soils, the cation exchange capacity was 24.06 milliequivalents per 100 grams; exchangeable calcium, magnesium, and potassium, 6.94, 5.32, and 0.86 milliequivalents per 100 grams, respectively; base saturation, 54.6 percent; and calcium saturation, 27.91 percent. The average for 13 samples of brown to dark brown soils was: cation exchange capacity, 27.63 milliequivalents per 100 grams; exchangeable calcium, magnesium, and potassium, 10.84, 6.56, and 1.02 milliequivalents per 100 grams, respectively; base saturation 67.1 percent; and calcium saturation 39.21 percent. Hence, in general, the brown and dark brown soils are slightly less leached of their bases than the reddish brown soils.

In view of the relatively low pH (pH range of 4.7 to about 6.0), the low percentage of exchangeable calcium (average for the reddish brown soils of 27.9 percent, and for the brown to dark brown soils of 39.2 percent), the relatively low calcium-magnesium ratio (1.26 for the reddish brown soils, and 1.54 for the brown and dark brown soils), and in view of the not necessarily always high but generally sufficient potassium, it would appear that these soils would be benefitted by the use of lime.

In support of the use of lime on these soils, a field experiment (34) can be cited which involved both lime and phosphorus on a reddish brown clay. The treatments consisted of no fertilizer, superphosphate, lime, and lime and superphosphate for alfalfa. The respective yields of alfalfa hay were 2480, 3720, 3060, and 8780 pounds per acre. It should be stated that laboratory data (34) show that these soils are often deficient in available phosphorus. The above soil was low in available phosphorus and had a pH of 5.6. The limed plot had a pH of 6.5, and the lime-phosphated plot had a pH of 6.8.

Out of 49 soil samples examined, 8 had a range of 39 to 93 ppm potassium, which means that the soils represented by these 8 samples are likely to respond to potash fertilizers (4, 33). The other 41 samples showed a range in ppm potassium above the threshhold for response to potash fertilization (4, 33).

In view of the quantity of exchangeable magnesium and the calcium-magnesium ratios determined for these soils (see Table 5), the magnesium supply appears to be satisfactory (4). Since the quantity of exchangeable sodium is of a magnitude of 0 to 0.43 milliequivalents per 100 grams of soil, amounting to 0 to 99 ppm, it presents no problem.

# TABLE 1

## Cation Data on Some Dark (Blackland) Clay Soils

| Soil No. | Location | Texture | Clay % | Color | | pH | CEC | Ca | Mg | K | Na | Total Bases |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Dry | Moist | | Milliequivalents per 100 grams | | | | | |
| 22 | Ambo | Clay | 70 | 10 YR 3/1 | 10 YR 3/1 | 7.8 | 54.86 | 46.40 | 11.80 | 2.74 | 0.29 | 61.23* |
| 13 | Alemaya College | Clay | 61 | 7.5 YR 4/0 | 7.5 YR 3/0 | 7.4 | 57.02 | 45.55 | 13.48 | 1.46 | 0.14 | 60.63* |
| 138 | Alemaya College | Clay | -- | 10 YR 3/1 | 10 YR 2/1 | 7.4 | 57.64 | 46.30 | 11.03 | 1.44 | 0.19 | 58.96* |
| 14 | Ejere | Clay | 62 | 10 YR 4/1 | 10 YR 2/1 | 7.3 | 53.12 | 32.67 | 18.20 | 1.85 | 0.58 | 53.30* |
| 26 | S. Combolcia | Clay | 60 | 10 YR 4/1 | 10 YR 3/1 | 6.8 | 53.84 | 36.80 | 18.53 | 2.17 | 0.24 | 57.74* |
| 19 | Bishoftu 67 km. Modjo | Clay | 54 | 10 YR 3/1 | 10 YR 3/2 | 6.8 | 48.71 | 33.60 | 10.11 | 3.47 | 0.36 | 47.54 |
| 53 | N. Combolcia | Clay | 49 | 5 YR 3/1 | 5 YR 2/1 | 6.8 | 44.59 | 26.40 | 13.79 | 3.48 | 0.23 | 43.89 |
| 55 | Quoram | Clay | 64 | 10 YR 4/1 | 10 YR 3/1 | 6.7 | 55.41 | 17.60 | 33.71 | 0.79 | 0.59 | 52.69 |
| 50 | S. Combolcia | Clay | 60 | 10 YR 4/1 | 10 YR 3/1 | 6.6 | 61.06 | 36.00 | 23.31 | 1.44 | 0.35 | 61.10 |
| 18 | Wongi | Clay | 76 | 10 YR 4/1 | 10 YR 3/1 | 6.5 | 59.74 | 32.50 | 18.50 | 2.70 | 0.72 | 54.42 |
| 144 | Ghibai | Clay | -- | 10 YR 4/1 | 10 YR 2/1 | 6.5 | 36.17 | 23.30 | 7.33 | 0.89 | 3.52 | 35.04 |
| 143 | Ghibai | Clay | -- | 7.5 YR 3/0 | 10 YR 2/1 | 6.4 | 58.55 | 40.70 | 10.69 | 1.25 | 4.02 | 56.66 |
| 141 | Ghibai | Clay | -- | 10 YR 4/1 | 10 YR 3/1 | 6.35 | 45.96 | 27.40 | 17.16 | 0.53 | 0.25 | 45.34 |

TABLE 1 (Continued)

| Soil No. | Location | Texture | Clay % | Color | | pH | CEC | Ca | Mg | K | Na | Total Bases |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Dry | Moist | | Milliequivalents per 100 grams | | | | | |
| 139 | Bishoftu<br>55 km. Modjo | Clay | -- | 7.5 YR 3/0 | 10 YR 3/1 | 6.3 | 54.64 | 32.35 | 15.33 | 3.19 | 0.32 | 51.19 |
| 145 | Ghibai | Clay | -- | 2.5 YR 3/0 | 2.5 YR 2/0 | 6.2 | 53.99 | 35.25 | 11.91 | 1.60 | 2.02 | 50.78 |
| 46 | Bahar Dar | Clay | 67 | 2.5 YR 4/0 | 2.5 YR 3/0 | 6.2 | 61.41 | 41.73 | 21.27 | 1.23 | 0.21 | 64.44* |
| 24 | Ghibai | Clay | 67 | 10 YR 3/1 | 10 YR 2/1 | 6.1 | 60.97 | 41.60 | 15.41 | 2.37 | 0.68 | 60.06 |
| 1 | Bishoftu<br>Exp. Station | Clay | 54 | 10 YR 4/1 | 10 YR 3/1 | 6.0 | 45.16 | 26.40 | 15.05 | 1.66 | 0.20 | 43.31 |
| 2 | Ghibai | Clay | 67 | 2.5 YR 3/0 | 2.5 YR 3/0 | 5.75 | 63.67 | 42.60 | 16.44 | 2.58 | 0.28 | 61.90 |
| 60 | Chercos | Clay | 57 | 5 YR 4/1 | 5 YR 4/1 | 5.5 | 62.89 | 33.38 | 24.50 | 0.84 | 0.24 | 58.96 |
| 59 | Gorgora | Clay | 63 | 2.5 YR 3/0 | 2.5 YR 3/0 | 5.3 | 60.26 | 27.20 | 24.67 | 0.66 | 0.37 | 52.90 |
| 5 | Gorgora | Clay | 65 | 2.5 YR 2/0 | 10 YR 3/1 | 4.9 | 61.55 | 30.00 | 26.64 | 1.69 | 0.26 | 58.59 |

CEC = Cation exchange capacity.

*Cations extracted with ammonium acetate exceed the exchange capacity.

## TABLE 2

## Cation and Cation Ratio Data on the Dark Clay Soils (Calculated from the data in Table 1)

| Soil No. | Ca + Mg * % | $\frac{Ca}{Mg}$ | $\frac{Ca + Mg}{K}$ | Ca * % | Ca ppm | Mg ppm | K ppm |
|---|---|---|---|---|---|---|---|
| 22 | 106.09 | 3.93 | 21.24 | 84.6 | 9280 | 1434 | 1071 |
| 13 | 103.53 | 3.38 | 40.43 | 79.9 | 9110 | 1639 | 570 |
| 138 | 99.46 | 4.20 | 39.81 | 80.3 | 9260 | 1341 | 563 |
| 14 | 88.25 | 1.80 | 27.50 | 61.5 | 6534 | 2213 | 723 |
| 26 | 104.16 | 1.99 | 25.50 | 68.4 | 7360 | 2253 | 848 |
| 19 | 89.74 | 3.32 | 12.60 | 69.0 | 6720 | 1229 | 1356 |
| 53 | 90.13 | 1.91 | 11.55 | 59.2 | 5280 | 1676 | 1360 |
| 55 | 92.60 | 0.52 | 64.95 | 31.8 | 3520 | 4099 | 308 |
| 50 | 97.13 | 1.54 | 41.19 | 59.0 | 7200 | 2834 | 563 |
| 18 | 85.37 | 1.76 | 18.89 | 54.4 | 6500 | 2249 | 1055 |
| 144 | 84.68 | 3.18 | 34.42 | 64.4 | 4660 | 891 | 347 |
| 143 | 126.26 | 3.81 | 41.11 | 69.5 | 8140 | 1299 | 488 |
| 141 | 96.95 | 1.60 | 84.08 | 59.6 | 5480 | 2086 | 207 |
| 139 | 87.26 | 2.11 | 14.95 | 59.2 | 6470 | 1864 | 1247 |
| 145 | 87.35 | 2.96 | 29.48 | 65.3 | 7050 | 1448 | 625 |
| 46 | 102.59 | 1.96 | 51.22 | 68.0 | 8346 | 2586 | 480 |
| 24 | 93.51 | 2.70 | 24.06 | 68.2 | 8320 | 1873 | 926 |
| 1 | 91.78 | 1.75 | 24.97 | 58.5 | 5280 | 1830 | 649 |
| 2 | 92.73 | 2.59 | 22.88 | 66.9 | 8520 | 1999 | 1008 |
| 60 | 92.03 | 1.36 | 68.90 | 53.1 | 6676 | 2979 | 328 |
| 59 | 86.08 | 1.10 | 78.59 | 45.1 | 5440 | 2999 | 258 |
| 5 | 92.02 | 1.13 | 33.52 | 48.7 | 6000 | 3239 | 660 |
| Average | 94.98 | 2.30 | 36.90 | 61.1 | 6870 | 2089 | 711 |

*Percent exchange capacity.

TABLE 3

Cation Data on Some Dark Soil Profiles

| Depth (inches) | Texture | | | Color | | pH | CEC | Ca | Mg | K | Na | Total Bases |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | Dry | Moist | | Milliequivalents per 100 grams | | | | | |
| A. 67 km. from Addis Ababa between Bishoftu and Modjo | | | | | | | | | | | | |
| 0-8 | 28 | 18 | 54 | 10 YR 3/1 | 10 YR 3/2 | 6.8 | 48.71 | 33.60 | 10.11 | 3.47 | 0.36 | 47.54 |
| 8-30 | 30 | 24 | 46 | 10 YR 3/1 | 10 YR 3/2 | 7.3 | 46.22 | 39.07 | 11.91 | 3.74 | 1.69 | 56.41* |
| 30-42 | 30 | 20 | 50 | 10 YR 3/1 | 10 YR 3/2 | 7.7 | 51.55 | 45.47 | 16.88 | 3.29 | 5.27 | 70.91* |
| 42-48 | 30 | 12 | 58 | 10 YR 4/1 | 10 YR 3/2 | 7.6 | 48.82 | 39.20 | 15.34 | 2.94 | 6.30 | 63.78* |
| B. 55 km from Addis Ababa between Bishoftu and Modjo | | | | | | | | | | | | |
| 0-8 | -- | -- | -- | 7.5 YR 3/0 | 10 YR 3/1 | 6.3 | 54.64 | 32.35 | 15.33 | 3.19 | 0.32 | 51.19 |
| 8-18 | -- | -- | -- | 7.5 YR 4/0 | 10 YR 2/1 | 6.5 | 54.62 | 33.73 | 16.33 | 3.11 | 0.37 | 53.54 |
| 18-24 | 19 | 13 | 68 | 10 YR 3/1 | 10 YR 3/1 | 6.8 | 56.08 | 29.50 | 14.80 | 3.40 | 0.74 | 48.44 |
| 36-48 | 26 | 10 | 64 | 10 YR 4/1 | 10 YR 4/1 | 7.7 | 53.87 | 39.15 | 20.72 | 5.02 | 2.82 | 67.71* |
| C. Ejere Area | | | | | | | | | | | | |
| 0-30 | 20 | 18 | 62 | 10 YR 4/1 | 10 YR 2/1 | 7.3 | 53.12 | 32.67 | 18.20 | 1.85 | 0.58 | 53.30* |
| 30-40 | 14 | 43 | 42 | 10 YR 4/1 | 10 YR 2/1 | 8.0 | 54.23 | 42.00 | 20.22 | 2.25 | 0.54 | 65.01* |
| 40-84 | 16 | 44 | 40 | 10 YR 3/1 | 10 YR 3/2 | 8.0 | 46.97 | 59.00 | 18.75 | 1.71 | 0.93 | 80.39* |

TABLE 3 (Continued)

| Depth | Texture | | | Color | | | CEC | Ca | Mg | K | Na | Total Bases |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (inches) | Sand | Silt | Clay | Dry | Moist | pH | Milliequivalents per 100 grams | | | | | |
| D. Ghibai Area - 16 km. northwest of lumber camp - 163 km. from Addis Ababa on Jimma Highway | | | | | | | | | | | | |
| 0-12 | 17 | 16 | 67 | 10 YR 3/1 | 10 YR 2/1 | 5.9 | 60.97 | 41.60 | 15.41 | 2.37 | 0.68 | 60.06 |
| 12-24 | 17 | 20 | 63 | 10 YR 2/1 | 10 YR 2/1 | 6.6 | 56.81 | 36.00 | 12.82 | 2.40 | 1.74 | 52.96 |
| 24-36 | 15 | 16 | 69 | 10 YR 3/1 | 10 YR 3/1 | 7.4 | 64.18 | 43.60 | 16.12 | 3.35 | 2.61 | 65.68* |
| E. College Farm - Blackland (Alemaya) | | | | | | | | | | | | |
| 0-8 | 21 | 28 | 61 | 7.5 YR 4/0 | 7.5 YR 3/0 | 7.4 | 57.02 | 45.55 | 13.48 | 1.46 | 0.14 | 60.63* |
| 12-24 | 17 | 20 | 63 | 2.5 YR 3/0 | 2.5 YR 2/0 | 6.8 | 45.91 | 29.47 | 14.91 | 0.99 | 0.41 | 45.78 |

*Cations extracted with ammonium acetate exceed the exchange capacity.

## TABLE 4

### Cation Data on Some Reddish Brown, Dark Brown, and Brown Soils*

| Soil No. | Location | Texture | Clay % | Color | | pH | CEC | Ca | Mg | K | Na | Total Bases | Base Sat. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Dry | Moist | | Milliequivalents per 100 grams | | | | | | |
| | | | | | **A. Reddish Brown Soils** | | | | | | | | |
| 3 | Lekempti Hwy 185 km. AA | Clay | 47 | 5 YR 4/3 | 5 YR 3/3 | 5.6 | 25.61 | 9.90 | 7.01 | 2.43 | 0.23 | 19.57 | 76.4 |
| 4 | Jimma Geran Farm | Clay | 56 | 5 YR 4/4 | 5 YR 3/3 | 5.8 | 22.83 | 10.20 | 6.69 | 2.00 | 0.20 | 19.19 | 84.0 |
| 6 | Entoto | Clay | 49 | 5 YR 4/6 | 2.5 YR 3/4 | 5.4 | 24.27 | 8.30 | 7.89 | 1.05 | 0.13 | 17.37 | 71.5 |
| 8 | Marewe W. of Bahar Dar | Clay | 47 | 5 YR 4/4 | 5 YR 3/4 | 5.3 | 28.07 | 8.70 | 7.73 | 0.66 | 0.09 | 17.18 | 61.2 |
| 23 | Agaro | Clay | 54 | 5 YR 3/4 | 5 YR 3/3 | 5.2 | 26.67 | 4.85 | 4.95 | 0.45 | 0.16 | 10.41 | 39.0 |
| 31 | Jimma | Clay | 50 | 5 YR 3/3 | 5 YR 3/3 | 5.7 | 27.03 | 5.50 | 4.65 | 0.43 | 0.15 | 10.73 | 39.7 |
| 35 | Asella | Clay | 42 | 5 YR 3/4 | 5 YR 3/3 | 6.0 | 23.54 | 7.40 | 5.10 | 1.12 | 0.17 | 13.79 | 58.6 |
| 41 | Lekempti Hwy 180 km. AA | Sc | 37 | 5 YR 4/4 | 5 YR 3/4 | 5.2 | 24.89 | 6.35 | 5.80 | 2.09 | 0.21 | 14.45 | 58.0 |
| 43 | Managasha Nursery | Clay | 50 | 5 YR 4/3 | 5 YR 3/3 | 6.3 | 25.00 | 8.90 | 7.40 | 1.51 | 0.13 | 13.34 | 53.3 |
| 65 | Jimma-Saka | Clay | 44 | 5 YR 4/4 | 2.5 YR 3/4 | 5.25 | 25.80 | 5.50 | 4.40 | 0.51 | 0.43 | 10.88 | 42.1 |
| 146 | Entoto | Cl | -- | 5 YR 4/3 | 5 YR 3/3 | 4.75 | 20.43 | 3.80 | 3.37 | 0.58 | 0.04 | 7.79 | 38.1 |

TABLE 4 (Continued)

| Soil No. | Location | Tex- ture | Clay % | Color |  | pH | CEC | Ca | Mg | K | Na | Total Bases | Base Sat. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Dry | Moist |  | Milliequivalents per 100 grams |  |  |  |  |  |  |
| 147 | Entoto | Cl | -- | 5 YR 4/6 | 2.5 YR 3/6 | 5.4 | 23.34 | 9.10 | 6.17 | 0.54 | 0.11 | 15.92 | 68.2 |
| 148 | Entoto | Cl | -- | 10 YR 5/4 | 10 YR 3/4 | 5.25 | 21.49 | 8.90 | 5.51 | 0.58 | 0.05 | 15.04 | 70.0 |
| 69 | W. Lekempti 10 km. | Cl | -- | 10 YR 4/2 | 5 YR 3/2 | 4.9 | 25.48 | 4.00 | 3.70 | 2.42 | 0.15 | 10.27 | 40.3 |
| 104 | W. Lekempti 20 km. | Cl | -- | 5 YR 4/3 | 5 YR 3/3 | 4.9 | 25.68 | 3.86 | 3.25 | 1.08 | 0.12 | 8.31 | 32.3 |
| 70 | W. Lekempti 30 km. | Cl | -- | 10 YR 4/3 | 5 YR 3/2 | 5.0 | 24.89 | 4.25 | 3.17 | 0.72 | 0.15 | 8.29 | 33.3 |
| 106 | W. Lekempti 50 km. | Cl | -- | 5 YR 3/4 | 5 YR 3/3 | 5.5 | 19.46 | 6.35 | 5.57 | 0.21 | 0.15 | 12.28 | 63.1 |
| 71 | W. Lekempti 60 km. | Scl | -- | 10 YR 4/3 | 5 YR 3/2 | 5.0 | 9.58 | 1.91 | 1.89 | 0.28 | 0.22 | 4.29 | 44.8 |
| 107 | W. Lekempti 70 km. | Scl | -- | 5 YR 4/4 | 5 YR 3/4 | 4.8 | 13.12 | 2.03 | 2.57 | 0.17 | 0.13 | 4.90 | 37.3 |
| 108 | W. Lekempti 80 km. | Cl | -- | 5 YR 5/4 | 5 YR 3/4 | 5.0 | 13.30 | 1.30 | 1.57 | 0.20 | 0.11 | 3.20 | 24.1 |
| 110 | W. Lekempti 110 km.<br>E. Ghimbi 10 km. | Cl | -- | 5 YR 4/4 | 5 YR 3/4 | 5.4 | 19.15 | 5.50 | 4.44 | 0.43 | 0.00 | 10.37 | 54.1 |
| 73 | Near Ghimbi | Cl | -- | 7.5 YR 4/4 | 5 YR 3/3 | 4.7 | 25.21 | 4.52 | 3.64 | 0.30 | 0.17 | 8.63 | 34.2 |

TABLE 4 (Continued)

| Soil No. | Location | Tex-ture | Clay % | Color |  | pH | CEC | Ca | Mg | K | Na | Total Bases | Base Sat. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Dry | Moist |  | Milliequivalents per 100 grams |  |  |  |  |  |  |
| 111 | Ghimbi-Yubdo 10 km. Ghimbi | Clay | -- | 5 YR 4/3 | 5 YR 3/2 | 5.2 | 23.36 | 7.40 | 3.79 | 0.61 | 0.11 | 11.91 | 50.9 |
| 112 | Ghimbi-Yubdo 20 km. Ghimbi | Cl | -- | 5 YR 4/3 | 5 YR 3/3 | 5.0 | 22.81 | 5.50 | 5.09 | 0.43 | 0.00 | 11.02 | 48.3 |
| 74 | Ghimbi-Yubdo 30 km. Ghimbi | Cl | -- | 7.5 YR 4/6 | 5 YR 3/3 | 5.8 | 16.52 | 6.10 | 4.77 | 0.10 | 0.10 | 11.07 | 60.0 |
| 113 | Ghimbi-Yubdo 40 km. Ghimbi | Cl | -- | 5 YR 4/4 | 5 YR 3/2 | 5.3 | 27.78 | 6.05 | 5.60 | 2.45 | 0.11 | 14.21 | 51.1 |
| 114 | Ghimbi-Yubdo 50 km. Ghimbi | Cl | -- | 5 YR 4/3 | 5 YR 3/3 | 5.1 | 25.21 | 7.00 | 4.77 | 1.23 | 0.11 | 13.11 | 52.0 |
| 75 | Ghimbi-Yubdo 60 km. Ghimbi | Cl | -- | 10 YR 4/3 | 5 YR 3/2 | 5.3 | 30.81 | 7.50 | 5.58 | 0.30 | 0.10 | 13.48 | 43.7 |
| 115 | Ghimbi-Yubdo 70 km. Ghimbi | Scl | -- | 5 YR 3/3 | 5 YR 2/2 | 5.0 | 29.56 | 5.97 | 4.52 | 0.31 | 0.10 | 10.90 | 37.2 |
| 116 | Ghimbi-Yubdo 80 km. Ghimbi | Scl | -- | 5 YR 3/3 | 5 YR 2/2 | 6.0 | 33.04 | 15.00 | 9.70 | 0.74 | 0.04 | 25.48 | 77.1 |
| 76 | Ghimbi-Yubdo 90 km. Ghimbi | Cl | -- | 5 YR 4/4 | 5 YR 2/2 | 5.15 | 29.33 | 7.30 | 5.43 | 0.92 | 0.11 | 13.76 | 46.8 |
| 118 | Near Birber River 110 km. Ghimbi | Clay | -- | 5 YR 3/3 | 5 YR 3/2 | 5.6 | 29.53 | 11.85 | 13.11 | 0.24 | 0.14 | 25.34 | 85.8 |

TABLE 4 (Continued)

| Soil No. | Location | Texture | Clay % | Color | | pH | CEC | Ca | Mg | K | Na | Total Bases | Base Sat. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Dry | Moist | | Milliequivalents per 100 grams | | | | | | |
| 77 | W. Yubdo 7 km. | Clay | -- | 5 YR 4/4 | 5 YR 3/3 | 4.9 | 25.94 | 4.55 | 3.70 | 0.24 | 0.16 | 8.65 | 33.3 |
| 78 | W. Yubdo 35 km. | Scl | -- | -- | 5 YR 2/2 | 5.2 | 30.85 | 5.15 | 4.60 | 1.37 | 0.15 | 11.27 | 36.5 |
| 122 | Yubdo-Dembidolo 10 km. E. Tankia | Clay | -- | 5 YR 3/2 | 5 YR 3/2 | 6.0 | 26.70 | 13.90 | 7.07 | 1.24 | 0.07 | 22.28 | 83.4 |
| 124 | Yubdo-Dembidolo 18 km. W. Tankia | Clay | -- | 5 YR 3/3 | 5 YR 2/2 | 5.9 | 29.83 | 15.57 | 7.68 | 1.07 | 0.06 | 24.38 | 81.7 |
| B. Dark Brown and Brown Soils | | | | | | | | | | | | | |
| 72 | W. Lekempti 90 km. | Cl | -- | 10 YR 4/3 | 7.5 YR 3/2 | 5.4 | 12.43 | 3.25 | 2.88 | 0.36 | 0.08 | 6.57 | 52.8 |
| 109 | W. Lekempti 100 km. | Clay | -- | 7.5 YR 4/2 | 7.5 YR 3/2 | 5.5 | 15.94 | 5.30 | 3.62 | 0.56 | 0.04 | 9.52 | 59.7 |
| 119 | N. Dembidolo 113 km. | Scl | -- | 7.5 YR 3/2 | 7.5 YR 2/2 | 5.2 | 29.92 | 10.90 | 5.10 | 0.23 | 0.13 | 16.36 | 54.7 |
| 120 | N. Dembidolo 103 km. | Cl | -- | 7.5 YR 3/2 | 7.5 YR 2/2 | 5.5 | 33.02 | 9.50 | 6.74 | 0.23 | 0.17 | 16.64 | 50.4 |
| 121 | N. Dembidolo 83 km. | Clay | -- | 7.5 YR 3/2 | 7.5 YR 2/2 | 6.3 | 32.75 | 14.40 | 9.70 | 2.63 | 0.09 | 26.82 | 81.9 |

TABLE 4 (Continued)

| Soil No. | Location | Texture | Clay % | Color | | pH | CEC | Ca | Mg | K | Na | Total Bases | Base Sat. % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Dry | Moist | | Milliequivalents per 100 grams | | | | | | |
| 79 | Tankia Village<br>N. Dembidolo<br>63 km. | Cl | -- | 10 YR 3/3 | 10 YR 2/2 | 6.05 | 36.55 | 12.30 | 8.38 | 4.58 | 0.17 | 25.43 | 69.6 |
| 123 | N. Dembidolo<br>53 km. | Clay | -- | 7.5 YR 3/2 | 7.5 YR 2/2 | 6.3 | 32.11 | 15.65 | 8.22 | 0.57 | 0.11 | 24.55 | 76.4 |
| 125 | N. Dembidolo<br>23 km. | Clay | -- | 7.5 YR 4/2 | 7.5 YR 2/2 | 5.5 | 35.04 | 16.68 | 8.11 | 0.84 | 0.07 | 25.70 | 73.3 |
| 126 | N. Dembidolo<br>13 km. | Clay | -- | 7.5 YR 3/2 | 7.5 YR 2/2 | 5.3 | 35.01 | 17.00 | 8.72 | 0.82 | 0.13 | 26.67 | 76.1 |
| 81 | N. Dembidolo<br>about 3 km. | Clay | -- | 7.5 YR 3/2 | 10 YR 2/2 | 5.3 | 36.55 | 10.20 | 8.30 | 0.31 | 0.18 | 18.99 | 51.9 |
| 127 | S. Dembidolo<br>10 km. | Clay | -- | 7.5 YR 3/2 | 7.5 YR 2/2 | 5.6 | 33.11 | 12.90 | 7.53 | 0.93 | 0.06 | 21.41 | 64.7 |
| 128 | S. Dembidolo<br>20 km. | Cl | -- | 10 YR 2/2 | 10 YR 2/2 | 6.3 | 16.45 | 8.90 | 5.37 | 0.64 | 0.11 | 15.02 | 91.3 |
| 129 | S. Dembidolo | Scl | -- | 7.5 YR 5/4 | 7.5 YR 3/2 | 5.3 | 10.32 | 3.95 | 2.71 | 0.63 | 0.34 | 7.63 | 73.9 |

*These soils were collected between Lekempti and Gambela (see Figure 1) except Nos. 3,4,6,8,23,31,35,41,43, and 65.

AA = Addis Ababa; Base Sat. = base saturation; Cl = clay loam; Sc = sandy clay; Scl = sandy clay loam.

# TABLE 5

## Cation and Cation Ratio Data on Reddish Brown, Dark Brown, and Brown Soils (Calculated from the data presented in Table 4)

| Soil No. | Ca + Mg * % | $\frac{\text{Ca}}{\text{Mg}}$ | $\frac{\text{Ca + Mg}}{\text{K}}$ | Ca * % | Ca ppm | Mg ppm | K ppm |
|---|---|---|---|---|---|---|---|
| | | | **A. Reddish Brown Soils** | | | | |
| 3 | 66.02 | 1.41 | 6.96 | 38.6 | 1980 | 852 | 965 |
| 4 | 73.98 | 1.52 | 8.45 | 44.6 | 2040 | 813 | 782 |
| 6 | 66.70 | 1.05 | 15.42 | 34.2 | 1660 | 959 | 410 |
| 8 | 53.53 | 1.13 | 24.89 | 30.9 | 1740 | 939 | 258 |
| 23 | 36.82 | 0.98 | 21.82 | 18.2 | 970 | 601 | 175 |
| 31 | 37.55 | 1.18 | 23.60 | 20.3 | 1100 | 565 | 168 |
| 35 | 43.11 | 1.45 | 11.16 | 31.4 | 1480 | 620 | 437 |
| 41 | 50.22 | 1.09 | 5.81 | 25.5 | 1270 | 705 | 817 |
| 43 | 48.60 | 1.20 | 10.79 | 35.6 | 1780 | 899 | 590 |
| 65 | 63.17 | 1.02 | 19.41 | 21.3 | 1100 | 535 | 199 |
| 146 | 48.45 | 1.13 | 12.36 | 18.6 | 760 | 409 | 226 |
| 147 | 65.42 | 1.45 | 28.28 | 38.9 | 1820 | 750 | 211 |
| 148 | 71.05 | 1.62 | 24.85 | 41.4 | 1780 | 666 | 226 |
| 69 | 30.21 | 1.08 | 3.18 | 15.7 | 800 | 449 | 946 |
| 104 | 27.68 | 1.19 | 6.58 | 15.0 | 772 | 395 | 422 |
| 70 | 29.73 | 1.34 | 10.28 | 17.1 | 850 | 385 | 281 |
| 106 | 61.25 | 1.14 | 56.76 | 32.6 | 1270 | 677 | 82 |
| 71 | 39.66 | 1.01 | 3.57 | 20.0 | 382 | 229 | 109 |
| 107 | 35.06 | 0.79 | 27.06 | 15.5 | 406 | 312 | 66 |
| 108 | 21.57 | 0.83 | 14.35 | 9.7 | 260 | 190 | 78 |
| 110 | 51.90 | 1.24 | 23.12 | 28.7 | 1100 | 539 | 168 |

TABLE 5 (Continued)

| Soil No. | Ca + Mg<br>* % | Ca<br>Mg | Ca + Mg<br>K | Ca<br>* % | Ca<br>ppm | Mg<br>ppm | K<br>ppm |
|---|---|---|---|---|---|---|---|
| 73 | 32.36 | 1.24 | 27.20 | 17.9 | 904 | 442 | 117 |
| 111 | 47.90 | 1.95 | 18.34 | 31.6 | 1480 | 460 | 238 |
| 112 | 46.42 | 1.08 | 24.63 | 24.1 | 1100 | 618 | 168 |
| 74 | 65.79 | 1.28 | 8.70 | 36.9 | 1220 | 741 | 39 |
| 113 | 41.93 | 1.08 | 4.76 | 21.7 | 1210 | 735 | 957 |
| 114 | 46.68 | 1.47 | 9.57 | 27.7 | 1400 | 580 | 480 |
| 75 | 42.45 | 0.99 | 43.60 | 24.3 | 1500 | 678 | 117 |
| 115 | 35.48 | 1.32 | 33.84 | 20.2 | 1190 | 549 | 121 |
| 116 | 74.75 | 1.55 | 33.38 | 45.4 | 3000 | 1179 | 289 |
| 76 | 43.40 | 1.34 | 13.84 | 24.9 | 1460 | 660 | 359 |
| 118 | 84.52 | 0.90 | 104.00 | 40.1 | 2370 | 1594 | 93 |
| 77 | 31.80 | 1.23 | 34.38 | 17.5 | 910 | 449 | 93 |
| 78 | 31.60 | 1.11 | 7.12 | 16.7 | 1030 | 559 | 535 |
| 122 | 78.53 | 1.97 | 16.91 | 52.0 | 2780 | 859 | 484 |
| 124 | 77.94 | 2.03 | 21.73 | 52.2 | 3114 | 933 | 418 |
| | | | B. Dark Brown and Brown Soils | | | | |
| 72 | 49.31 | 1.13 | 17.03 | 26.1 | 650 | 350 | 140 |
| 109 | 55.95 | 1.46 | 15.93 | 33.2 | 1060 | 440 | 218 |
| 119 | 53.47 | 2.14 | 69.57 | 36.4 | 2180 | 620 | 89 |
| 120 | 49.18 | 1.41 | 70.61 | 28.7 | 1900 | 819 | 89 |
| 121 | 73.58 | 1.48 | 9.16 | 43.9 | 2880 | 1179 | 1028 |
| 79 | 56.58 | 1.47 | 4.52 | 36.6 | 2460 | 1019 | 1790 |
| 123 | 74.33 | 0.90 | 41.87 | 48.7 | 3130 | 999 | 222 |

### TABLE 5 (Continued)

| Soil No. | Ca + Mg *% | $\frac{\mathrm{Ca}}{\mathrm{Mg}}$ | $\frac{\mathrm{Ca} + \mathrm{Mg}}{\mathrm{K}}$ | Ca * % | Ca ppm | Mg ppm | K ppm |
|---|---|---|---|---|---|---|---|
| 125 | 70.70 | 2.06 | 29.50 | 47.6 | 3336 | 986 | 328 |
| 126 | 73.46 | 1.95 | 31.37 | 48.5 | 3400 | 1060 | 320 |
| 81 | 50.61 | 1.23 | 59.68 | 27.9 | 2040 | 1009 | 121 |
| 127 | 61.70 | 1.71 | 21.97 | 38.9 | 2580 | 915 | 362 |
| 128 | 86.74 | 1.66 | 22.30 | 54.1 | 1780 | 652 | 250 |
| 129 | 64.53 | 1.46 | 10.57 | 38.2 | 790 | 305 | 246 |

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*Percent exchange capacity.

TABLE 6

Cation Data on Some Reddish Brown Soil Profiles

| Depth (inches) | Texture | pH | CEC | Ca | Mg | K | Na | Total Bases | Base Sat. % |
|---|---|---|---|---|---|---|---|---|---|
| | | | Milliequivalents per 100 grams | | | | | | |
| Profile 1. West of Bahar Dar | | | | | | | | | |
| 0-10 | Clay | 5.3 | 28.07 | 8.70 | 7.73 | 0.66 | 0.09 | 17.18 | 61.2 |
| 10-20 | Clay | 5.4 | 24.12 | 7.40 | 5.75 | 0.46 | 0.11 | 13.72 | 44.4 |
| 20-40 | Clay | 5.3 | 23.39 | 6.20 | 5.43 | 0.53 | 0.11 | 12.27 | 52.5 |
| Profile 2. Near Asella | | | | | | | | | |
| 0-12 | Clay | 6.0 | 23.95 | 7.05 | 5.10 | 1.14 | 0.13 | 13.42 | 56.0 |
| 12-24 | Clay | 5.9 | 20.18 | 6.40 | 5.09 | 0.74 | 0.13 | 12.36 | 61.2 |
| 24-36 | Clay | 6.0 | 20.76 | 6.80 | 9.21 | 0.53 | 0.24 | 16.78 | 80.8 |
| 36-48 | Clay | 6.1 | 20.03 | 6.40 | 6.74 | 0.56 | 0.26 | 13.96 | 69.7 |
| 48-60 | Clay | 6.2 | 21.05 | 8.10 | 6.41 | 1.18 | 0.13 | 15.82 | 75.2 |
| 60-72 | Clay | 6.3 | 23.59 | 7.60 | 8.30 | 0.70 | 0.20 | 16.80 | 71.2 |
| Profile 3. Jimma-Saka Highway - Near Jimma | | | | | | | | | |
| 0-10 | Clay | 5.6 | 25.80 | 5.50 | 4.44 | 0.51 | 0.43 | 10.88 | 42.2 |
| 10-24 | Clay | 5.7 | 17.54 | 3.80 | 2.96 | 0.13 | 0.30 | 7.19 | 41.0 |
| 24-48 | Clay | 6.0 | 14.91 | 3.48 | 1.81 | 0.14 | 0.23 | 5.66 | 38.0 |
| Below 48 | Clay concretionary | 6.2 | 14.41 | 1.68 | 1.52 | 0.13 | 0.25 | 3.58 | 24.8 |
| Profile 4. Managasha Nursery | | | | | | | | | |
| 0-14 | Clay | 6.3 | 25.00 | 8.90 | 7.40 | 1.51 | 0.13 | 17.94 | 43.8 |
| 14-24 | Clay | 6.1 | 21.78 | 6.60 | 7.07 | 1.05 | 0.13 | 14.85 | 68.2 |
| 24-36 | Clay | 6.1 | 20.91 | 5.50 | 7.07 | 0.64 | 0.13 | 13.34 | 63.8 |
| 36-48 | Clay Loam | 5.9 | 19.01 | 4.00 | 3.62 | 0.74 | 0.04 | 8.40 | 44.2 |

# SUMMARY AND CONCLUSIONS

A number of representative soil samples of the blacklands and brown to reddish brown soils of Ethiopia were secured. Laboratory examinations of these samples consisted of determination of color, texture, pH, cation exchange capacity, and exchangeable calcium, magnesium, potassium, and sodium.

The results of the investigations are as follows:

A. Blackland Soils

1. These soils were all clayey in texture ranging up to as much as 76 percent clay.
2. The pH of the surface soils varied from 4.9 to 7.8. The pH increased with increasing depth.
3. The cation exchange capacity of these soils ranged from 36.17 to 63.67 milliequivalents per 100 grams. The average was 55.05 milliequivalents.
4. The cations extracted from these soils by ammonium acetate accounted for nearly all and in some cases more than the cation exchange capacity.
5. These soils were high in exchangeable potassium.

B. Reddish Brown, Dark Brown, and Brown Soils

1. The texture of these soils ranged from clay loam to clay for the most part, with a few exceptions.
2. The pH ranged from 4.7 to 6.3 for the surface soils; the profile is acid throughout its entire depth.

3. The cation exchange capacity ranged from 9.58 to 36.55 milliequivalents per 100 grams.
4. Some of these soils were low in exchangeable potassium.
5. Since the pH is low and since the calcium saturation is also found to be relatively low, these soils should respond to lime application, provided other deficiencies are corrected.

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