MORPHOLOGY AND GENESIS OF SOME WEAKLY DEVELOPED SOILS IN WESTERN OKLAHOMA

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MORPHOLOGY AND GENESIS OF SOME WEAKLY DEVELOPED

SOILS IN WESTERN OKLAHOMA

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INTRODUCTION

In recent years, people using soil have given more and more attention to what lies beneath the surface layer trying to understand plant growth response and engineering performance. Nowadays, growing recognition of the importance of subsoils to agriculture, forestry and engineering is encouraging people to look for information on subsoil properties and behavior.

Subsoil layers are extremely important to crop production, pasture management, forest growth, soil conservation, construction of highways, and airport runways.

Strictly, from an agricultural point of view, the subsoil deserves close attention, because it affects soil management anc crop production whether it underlies the normal surface layer or is exposed.

Deeper layers of the soil have important effects on moisture regimes and areation capacities. They may also supply certain plant nutrients; permeability of subsoil has a direct bearing on erosion hazards.

For better understanding of soil, a systematic examination of the chemical and physical properties is essential, and of prime importance. Time and economic factors do not allow soil scientists to examine each site; therefore, grouping of soil in a group of similar properties and that behave alike under certain management save time and repeatability to work. To accomplish this, soil must be sampled to the depth where the soil-forming factors have altered the parent material. These samples help studying the physical and chemical properties of the soil in the laboratory. It also helps the soil scientist draw a soil map that shows the soils locations and variations, besides the exchange of the knowledge about these soils with soil scientists in other places where similar soil may occur.

CHAPTER I

LITERATURE REVIEW

"Soil" as the term is used in soil science, is a collection of natural bodies occupying portions of the earth's surface, it has depth and shape

The properties that are displayed by the soil body are the result of the integrated effect of several external and internal factors acting upon the geologic material under widely different conditions. The most important of these factors, and as presented by Jenny (17) are:

1. Climate - Including temperature and moisture;
2. Living organisms - Including micro and macro organisms;
3. Age - Length of time through which the parent material has been subjected to the other soil forming factors;
4. Parent material;
5. Relief - Shape and topography of the earth's surface;

According to Jenny (17), these factors vary from place to place, and any change in one of these factors causes a corresponding change in the intensity of the others. As a result, the soil properties are determined by the dominant factor, or the combined effect of two or more. In addition to this, all these factors are found everywhere and act under any condition, but they act with different intensity imparting their imprint on the soil properties. In the arid environment (26), where the biological pressure is very low, the soil formation is characterized by a greatly reduced biochemical activity and the dominance of physical type of weathering. On the other hand, in the humid environment where the biological pressure is very high, the soil weathering is characterized by high biochemical activity and the dominance of chemical weathering.

Under the integrated effect of the soil forming factors, the parent material goes under changes which result in producing material that differ from the original one. The new material that has been chemically and physically changed in the presence of biologic factor is called "soil" (Marbut, 24).

Simonson (36) considered that horizons development can be due to four processes: addition, removal, transformation and translocation. These processes, which may offset or enhance the horizons differentiation, operate in all kinds of soils, but at different intensity. The relative importance of each process is not uniform in all soils. Some are intensive under certain conditions and weak under others.

The soil profile exhibits features that reflect the balanced action of all these processes together, or the dominant effect of one of these processes.

Normally, the effect of soil forming processes can be recognized by studying the soil profile which is considered as consisting of a number of different horizons (Hallsworth, 14). The distinction between the horizons usually being made in the field on the basis of some changes produced by soil forming processes. These changes may be either in color, structure or texture.

Difference in Color

Differences in color exhibited in the soil profile may be the result of many pedogenic processes. Melanization, the process of darkening of soil by addition of organic matter, is considered to be the most pronounced means of profile differentiation during the early stages of soil development (36, 14). The darkening happens as a result of root extension into the soil profile. Roots which are partially decayed, produce some relatively dark, stable compounds (10). The dark soil material sometimes is carried deep in the profile by the small living animals, or by falling off fresh organic material through the soil cracks (16, 36).

When excessive calcium ions occupy clay exchange sites. The organic matter is incorporated with clay fraction at the top of soil horizon. Under acid leaching conditions the organic matter is moved from the top of the soil profile and accumulated in the subsoil making the surface darker (40, 41). Furthermore, color difference can be brought to the soil profile due to the change in the chemical make-up of the iron bearing compound. Oxidation, reduction and hydration of these compounds result in corresponding change in color, or release of iron oxides (6, 9). Iron oxides may accumulate in the subsoil forming a strong color horizon (39). In addition to this, Gile (13) reported a change in the color as a result of calcium carbonate removal where soil becomes redder in the zone from which the calcium carbonate has been removed.

Difference in Texture

Chemical and physical weathering result in changing the nature of the parent material. The product of the weathering must either form a new mineral, by synthesis mechanisms, or remain as a residue where other constituents are moved out of the leaching zone (19, 10). The clay minerals are some of these resynthesized compounds. The clay minerals bear and determine, if not all, the most important physical and chemical properties of the soil (10).

A considerable time is required for the soil forming factors to build up a certain amount of clay material (17). Given enough time, the result of joint effect of soil forming factors is the difference in amount of clay between the solum and parent material.

The clay which is formed in the solum is subjected to elluviation and illuviation (36). As a result, the clay is moved from one horizon to another horizon. Thus, the horizon which is depleted from the clay become coarser in texture and the horizon which receive the illuviated clay becomes finer in texture (40). Brewer (7) found that the clay illuviation is an insignificant factor in causing the small proportion of clay in the upper horizon of Australian soil. He concluded from this that mechanisms other than clay elluviation must be involved in causing the particle-size differentiation, in at least some part of the profile, and suggested differential weathering as a possible explanation.

Given enough time, textural difference becomes one of the striking features of the soil. If weathering proceeds to an advanced stage, the clay may be destroyed and the textural difference between horizons becomes minimal (38, 40).

Sometimes textural difference can be exhibited by a soil profile of young age, even though the time is too short for the soil forming processes to operate on the parent material. These conditions can happen as the result of sudden deposition by wind or water activity (40).

Difference in Structures

Mineral soil is composed of sand, silt and clay. Structure involves binding individual soil particles to individual aggregates termed peds. Clay particles, organic matter and iron oxides are responsible for binding soil separates together. The accumulation of organic matter in the soil and its type of decay play a major role, especially in the development of granular structure common in the surface of the soil (6). Clay content may also play an important role in the formation of blocky, prismatic and columnar structure. Some soil in the tropical regions however, are low in organic matter, yet they are well aggregated. This appears to result from cementation by iron oxides. If the clay percentage in the soil profile is considered as a function of soil forming factors acting on the parent material and if the accumulation (17) of organic matter is the result of the biological forces developing in the solum, then it is reasonable to assume that after a certain time that the solum will develop structural properties different from that of the parent material.

Soil forming processes rearrange the clay and organic matter in the profile by translocation. These processes cause some horizons to be higher in clay content or organic matter. Consequently, stronger structure develops in this horizon as in the development of elluviated and illuviated horizons (40).

If the parent material is extremely weathered so that the alteration is complete, the soil developed on it shows the near total depletion of the silicate clay. In this case the soil profile is structurally rather featureless except of some aggregation results from the cementation by iron oxides (38, 18, 40).

It has been universally recognized, since Dokuchyaev had established the modern soil science, that living organisms are a major factor in soil development. Even soil scientists are inclined to differentiate between soil and the parent material by using the biologic factor to divide the soil profile to a biologic and non biologic zone (36, 17).

The living organisms play two contradictory roles in the soil development. The first is through the unique effect of organic matter accumulation producing the dark color of topsoil (4), which is termed melanization, and by clay illuviation which is important processes in profile differentiation (11). On the other hand, living organisms (vegetation and animals) play a considerable role in offsetting profile differentiation. Vegetation may reduce the extent of profile differentiation depending on type and amount of organic matter that is returned to the soil and the cations brought by the roots from the subsoil (10). In this case, cations levels are maintained, and their leaching is minimized. This helps to keep the clay in flocculated condition and reduces illuviation.

Different kinds of small animals that inhabit the soil influence profile development. Earthworms are active in converting plant residue to humus and mixing it with soil. They also carry organic matter deep into subsoil and fresh mineral to surface horizons. Doing this, they leave tunnels which facilitate movements of water through the soil. In many cases, they were found to be responsible for destroying the structure of the soil.

Ants also (41) cut out fragments of plants and store them in underground chambers to be used for food. In sub-humid and semi-arid regions, red ants build chambered nests beneath the surface and move the excavated material above the surface. Ant hills, which are built from fine earth mixed with fine gravel brought up from subsoil are another example of ants activity. Fragments of argillian material have been observed in thin microscope sections of material from large ant mounds (5). These ant hills are destroyed and rebuilt each year. Therefore one can recognize the smount of soil material kept in cycle as a result of ant activity.

Termites also gather vegetation from the neighborhood and store them in their nest. In many cases (41, 15), it has been found that the termites' mounds have a high concentration of lime even in highly leached soil. It is hypothesized that the concentration of calcium carbonate results from the removal of the subsoil up to the surface.

Burrowing animals, mammals, gophers, rodents and prairie dogs, were observed to be active in moving subsoil upward, churning and rejuvenating the entire soil.

In addition to the animal activity, many other agents help in mixing the soil (4): Mixing by plant, freeze-thawing cycle, movement of gases in the soil, and vibration notably earthquakes tremors. Mixing of soil material could result due to the presence of certain types of clay minerals that have high shrink-swell potential (37). These clay minerals are responsible for churning the soil material when they are present in a considerable amount. The result of shrinking and swelling through repeated cycle of wetting and drying is that soil material is kept moving upward and downward. This retard horizon development.

Ruhe (32) observed that no clay skins are present in the Bt horizon with high shrink-swell potential where the plasmic fabrics show that the horizon have been under stress.

In another case, shrkinking and swelling was observed to prevent the formation of clay skins and may destroy pre-existing ones. Hence, clay (32) is illuviated but clay skins are not found. This makes the recognition of the argillic horizon more difficult.

The absence of clay skins has been reported in the argillic horizon of Mohave soil (3). It has been attributed to natural pedoturbation. Preliminary studies showed that it was possible to distinquish between coating of illuviated clay and stress-oriented clay formed in place in a moderately fine of fine textured soil.

Nettleton et. al. (27) also found that the destruction of clay skin is related to shrink-swell potential. They observed that clay skins are absent in horizons having a shrink-swell potential of more than 4 percent.

CHAPTER II

MATERIAL

Climate and Vegetation

Washita County vegetative cover is dominantly mixed grasses. The county located in the zone of subhumid climate with low humidity and a wide range in temperature between summer and winter. The mean annual precipitation is 30 inches, and most of it falls during the growing season. Winter has the lowest seasonal rainfall. The average annual temperature is 60.8^{o}F. The prevailing winds blow from the south and northwest (39). Figures 1 and 2 show the average annual precipitation, vegetation and evapotranspiration.

Geology

The soils are developed from material deposited during three geological periods: The Permian, the Tertiary, and the Quarternary. In most of the county the exposed "Red Beds" of Permian age have weathered to furnish the parent material for large areas of the soils (34, 32). The Quartermaster, Cloudchief Gypsum, Day creek, Dolomite and White Horse Sandstone are among the formations that influenced the development of the physical characteristics of the soils. Dill, Quinlan, Woodward, and Cordell soils are among soils developed on the Quartermaster Formation which is the most recent formation of Permian age in the county. The Doxey and Elk City are members of the Quartermaster

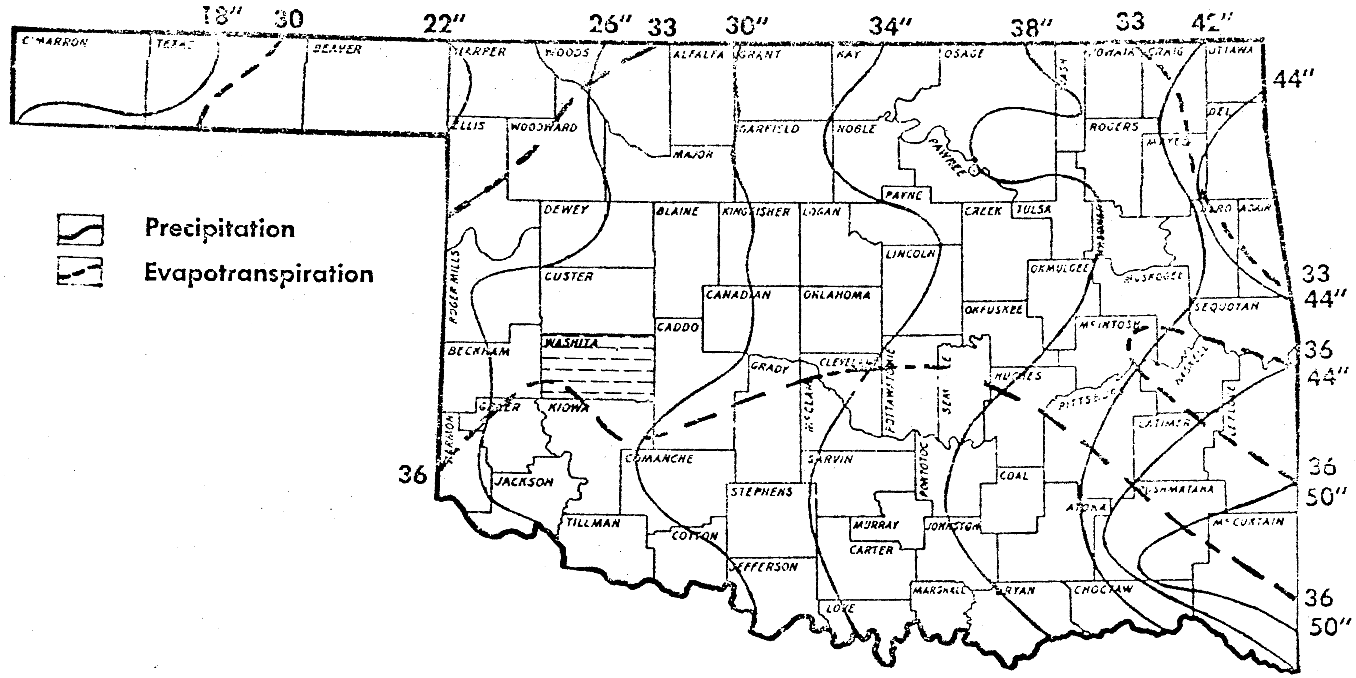

Figure 1. Average annual precipitation zones and potential evapotranspiration lines outlined by Thornthwaite.

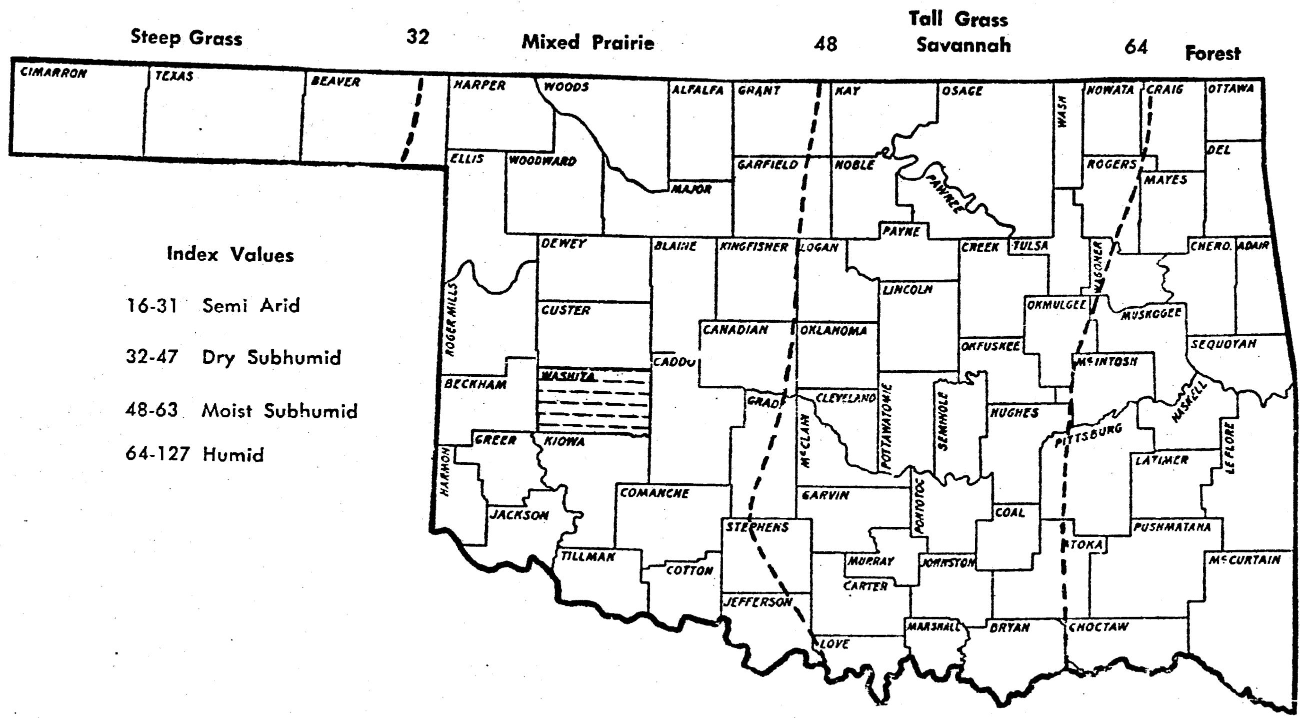

Figure 2. Average annual precipitation effectiveness index as estimated by Thornthwaite.

formation. The Doxey is the older member and the finest in texture. It is composed of stratified fine grained sandstone and siltstone or coarse grained shale. The Dill, Cordell, and Quinlan soils were developed in material derived from this formation and Woodward soils were influenced by this material.

The moderately coarse-textured Dill and Quinlan soils were developed in material derived from the Elk City member of the Quartermaster Formation which consists of medium grained and fine-grained sandstone. The Woodward soil was also influenced by this material. Grandfield soil has developed in the loose sands and sandy clay of Quarternary or Tertiary age which were deposited either by water or wind and overlie the Red Beds (1).

Profile Description

Cordell Silt Loam

Cordell soils developed on very gently sloping through moderately steep uplands. Slope gradients are 1-15 percent. The soil formed in material weathered from hard siltstone. The climate is dry subhumid with an average precipitation of about 23-28 inches and Thornthwaite annual P-E index are about 33-44. The mean annual temperature is from 57^{o} to about 65^{o}F.

Location. Photo no. CRB-1BB-286 Washita County, Oklahoma. This location is about 950 feet east and 200 feet south of the northwest corner of section II-T11N.R18W. 5 percent south facing slope in native grass in an area mapped Cordell-Rock outcrop complex. 2-15 percent slopes.

Soil profile description:

A 0-18 Reddish brown (3.5YR4/4) silt loam, dark reddish brown (2.5YR3/4) moist; moderate fine and medium granular structure, slightly hard, friable; many fine and medium roots; many worm casts, strong effervescence with HCL (pH8); gradual smooth boundary.

B21 18-28 Reddish brown (2.5YR4/4) silt loam, dark reddish brown (2.5YR3/4) moist; moderate medium and fine subangular blocky structure, hard, friable; many fine and medium roots; many worm casts; few fine fragments of siltstone; strong effervescence with HCL(pH8); clear wavy boundary.

B22 28-36 Reddish brown (2.5YR5/4) silt, dark reddish brown (2.5 YR3/4) moist; weak medium granular structure; hard; friable; many fine and medium roots; few insect casts; 70 percent by volume fragments of siltstone 1/4-1 inch diameter; strong effervescence with HCL(pH8); clear wavy boundary.

R 36-63 Red (2.5YR5/6) (hard siltsone), dark red (2.5YR3/6), moist; few roots between joints in siltstone; strong effervescence with HCL(pH8).

Parent material: Hard siltstone of Doxey formation.

Quinlan Loam

Quinlan occurs on nearly level through very steep upland. The slope is dominantly between 1-12 percent, but ranges from 0-50 percent. The series consists of a shallow reddish soil that developed under a cover of mid and tall grass. The parent material was derived from the Permian Red Beds. The parent rock is weakly consolidated red, calcareous sandstone or siltstone (Cloud Chief formation) that includes some clay stone. The Quinlan soil is associated with Woodward, Vernon and Dill soils. The climate is dry subhumid with a mean annual precipitation of about 30-32 inches and Thornthwaite annual P-E index of about 28-50. The mean annual temperature is from 57^{o} to about 65^{o}F.

Location. Photo no. CRB-2BB-74 Washita County, Oklahoma. About

1,600 feet south and 400 feet east of the northwest corner of section 18-T9N-R15N 8.5 percent west facing slope in native range.

Soil profile description:

A1	0-23	Reddish brown (5YR4/4) loam; dark reddish brown (5YR 3/4) moist; weak fine granular structure; slightly hard; very friable; many fine and medium roots; many fine pores; few fragments of sandstone; strong effervescence (pH8); clear wavy boundary.
B2	23-43	Reddish brown (2.5YR5/4) sandy loam; dark reddish brown (2.5YR3/4) moist; weak fine granular structure; slightly hard; very friable; many fine and medium root; common pores; common fragments of soft sandstone; strong effervescence with HCL(pH8); abrupt wavy boundary.
C	43-64	Red (2.5YR5/6) loam; dark red (2.5YR3/6) moist; few roots in fractures; cracks range from 4-24 inches apart; weakly cemented stratified sandstone; few fine roots; strong effervescence with HCL(pH8).

Parent material: Calcareous, weakly consolidated sandstone or siltstone of Cloud Chief formation.

Woodward Loam

This soil occurs on nearly level through moderately steep uplands. Slope gradients are dominantly between 1 and 12 percent but range from 0-20 percent. It developed under a cover of tall grasses. The Woodward series consists of reddish, silty or moderately sandy soils on upland, underlain by red bed or calcareous weakly consolidated sandstone. The climate is dry subhumid with a mean annual precipitation of about 20-29 inches and Thornthwaite annual P-E index of about 28-44. The mean annual temperature is from 57^{o} to about 65^{o}F. This soil is subject to both wind and water erosion.

Location. Photo no. CRS-2BB-74 Washita County, Oklahoma. About 1,900 feet south and 300 feet east of the northwest corner of section 18-T9N-$15W, 8 percent west facing slope in native range.

Soil profile description:

A	0-36	Reddish brown (5YR4/4) loam, dark reddish brown (5YR3/4) moist; moderate fine granular structure; slightly hard, very friable; many fine roots, many worm casts; calcareous; moderately alkaline, strong effervescence, clear smooth boundary.
B2	36-74	Red (2.5YR5/6) siltloam; dark red (2.5YR3/6) moist; weak coarse prismatic structure; slightly hard; very friable; many fine and medium roots; few fragments of soft sandstone; few krotovinas; few films of soft powdery lime; strong effervescence; moderately alkaline; clear smooth boundary.
B3	74-89	Light red (2.5YR6/6), silt loam; red (2.5YR4/6) moist; weak coarse prismatic structure; hard very friable; many worm casts; very few sandstone fragments; common fine roots; few films and small concentration of soft powdery lime; strong effervescence; moderately alkaline; clear wavy boundary.
C	89-119	Light red (2.5YR6/6) silt loam; weakly consolidated; stratified sandstone and siltstone; red (2.5YR4/6) moist; few fine roots; very few faint calcium carbonate concretions; moderate effervescence

Dill Very Fine Sandy Loam

Dill soil developed on undulating to nearly flat areas with occasional slight swell or low smoothly rounded ridges. This soil developed from a rather soft noncalcareous sandstone which is deeply buried in most places. On the virgin soil, the native vegetation is largely coarse bunch grasses including species of andropogon. Slope are 0-12 percent, but mainly between 1-5 percent. The climate is dry-subhumid. The mean annual precipitation is about 25 inches. Thornthwaite annual P-E index is about 40, and mean annual temperature is about 62^{o}F.

Location. Photo no. CRB-1BB-225, Washita County, Oklahoma. About 4,000 feet west and 600 feet south of the northeast corner of section 21-T11N-R19NW. About 600 feet northeast of Turkey Creek, site 7, 2 percent west facing slope in native range.

Soil profile description:

A11	0-10	Reddish brown (5YR4/4), very fine sandy loam; dark reddish brown (5YR3/4) moist; weak fine granular structure; hard; very friable; many coarse and medium roots; few fine pores; no effervescence with HCL(pH8); clear smooth boundary.
A12	10-36	Reddish brown (5YR4/4), very fine sandy loam; dark reddish brown (5YR3/4) moist; weak fine granular structure; hard; very friable; many fine and medium roots; common worm casts; no effervescence with HCL(pH7); gradual smooth boundary.
B21	36-53	Reddish brown (2.5YR4/4) very fine sandy loam; dark reddish brown (2.5YR3/4) moist; weak medium prismatic structure breaking to weak fine granular structure; hard; very friable many very fine and fine roots; common earthworm casts; few krotovinas; no effervescence with HCL(pH7); gradual smooth boundary.
B22	53-84	Reddish brown (2.5YR4/4); very fine sandy loam; dark reddish brown (2.5YR3/4) moist; weak medium prismatic structure breaking to weak fine granular structure; hard; very friable; many fine and medium roots; common worm casts; few krotovians; few fragments of soft sandstone; no effervescence with HCL(pH7); diffuse wavy boundary.
C	84-119	Red (10YR4/6); red (10YR4/5) moist; with thin band of dark red (2.5YR3/6) weakly cemented stratified sandstone that average loam. The bonds react strongly with HCL(pH8); few fine roots.

Parent material: Weakly cemented noncalcareous sandstone of the Elk City formation. Note: colors are for dry soil unless otherwise noted. Reaction determined by Hellige-Truog pH kit.

Grandfield Fine Sandy Loam

Grandfield soil occurs on nearly level to gently sloping soil on uplands. Slope gradients are 0-8 percent. This soil developed under a cover of mid and tall grasses. The parent material is loamy alluvium or aeolian sediments. It is generally neutral in reaction. The climate is dry subhumid. Average annual precipitation is 19-28 inches, annual

Thornthwaite P-E index is 28-44, and the mean annual temperature is about 59° to 65°F. Soil blowing and water erosion are hazards.

Location. Photo no. CRB-2BB-180, Washita County, Oklahoma. About 2,500 feet south and 200 feet east of the northwest corner of section 34-T10N-R18N. Undulating one percent slope in wheat field.

Soil profile description:

Ap 0-18 Reddish brown (5YR4/3); fine sandy loam; dark reddish brown (5YR3/3) moist; weak fine granular structure; hard; very friable; many fine and medium roots; few worm casts; no effervescence (pH7); abrupt wavy boundary.

B21t 18-33 Reddish brown (5YR4/4); fine sandy loam; dark reddish brown (5YR3/4); moist; moderate medium prismatic structure; hard; friable many fine and medium roots; few worm casts; clay films on ped faces; no effervescence (pH7); gradual smooth boundary.

B22t 33-76 Reddish brown (5YR4/4); fine sandy loam; dark reddish brown (5YR3/4) moist; moderate medium-coarse prismatic structure; hard; friable; common fine and medium roots; common worm casts; clay films on ped faces; clay film darker in matrix; no effervescence (pH7); clear smooth boundary.

B23t 76-122 Red (2.5YR4/6); fine sandy loam; dark red (2.5YR3/6) moist; moderate coarse prismatic structure; hard; very friable; many fine pores common fine and medium roots; few worm casts; clay films on ped faces; few krotovinas; no effervescence (pH7); gradual smooth boundary.

B3 122-155 Red (2.5YR4/6); loamy fine sand; dark red (2.5YR3/6) moist; weak coarse prismatic structure; slightly hard; very friable; common very fine and fine roots; common worm casts; few krotovinas; common pores; clay films on ped faces; no effervescence (pH7); clear smooth boundary.

IC 155-203 Red (2.5YR5/6); loamy fine sandy, red (5YR4/6) moist; weak coarse prismatic structure; slightly hard; very friable; common very fine and fine roots; common fine pores; common worms cast; few krotovinas; no effervescence (pH7) abrupt smooth boundary.

Parent material: Loamy alluvium or aeolian sediments.

IIC2 203-221 Dark reddish brown (2.5YR3/6) moist; sandy clay loam coarse moderate angular and subangular blocky; black oxides coating common fine pores; very few fine roots; very few faint fine calcium carbonate concretions; clay films; no effervescence with soil matrix; crushed sample give pH8; clear smooth boundary.

IIC3 221–279 Dark reddish brown (2.5YR3/6) moist; silty clay loam; coarse strong angular and subangular blocky; black oxides coating; clay films; strong pressure faces; few coarse calcium carbonates; very few earth worm casts; no effervescence with soil matrix; but crushed sample give (pH8).

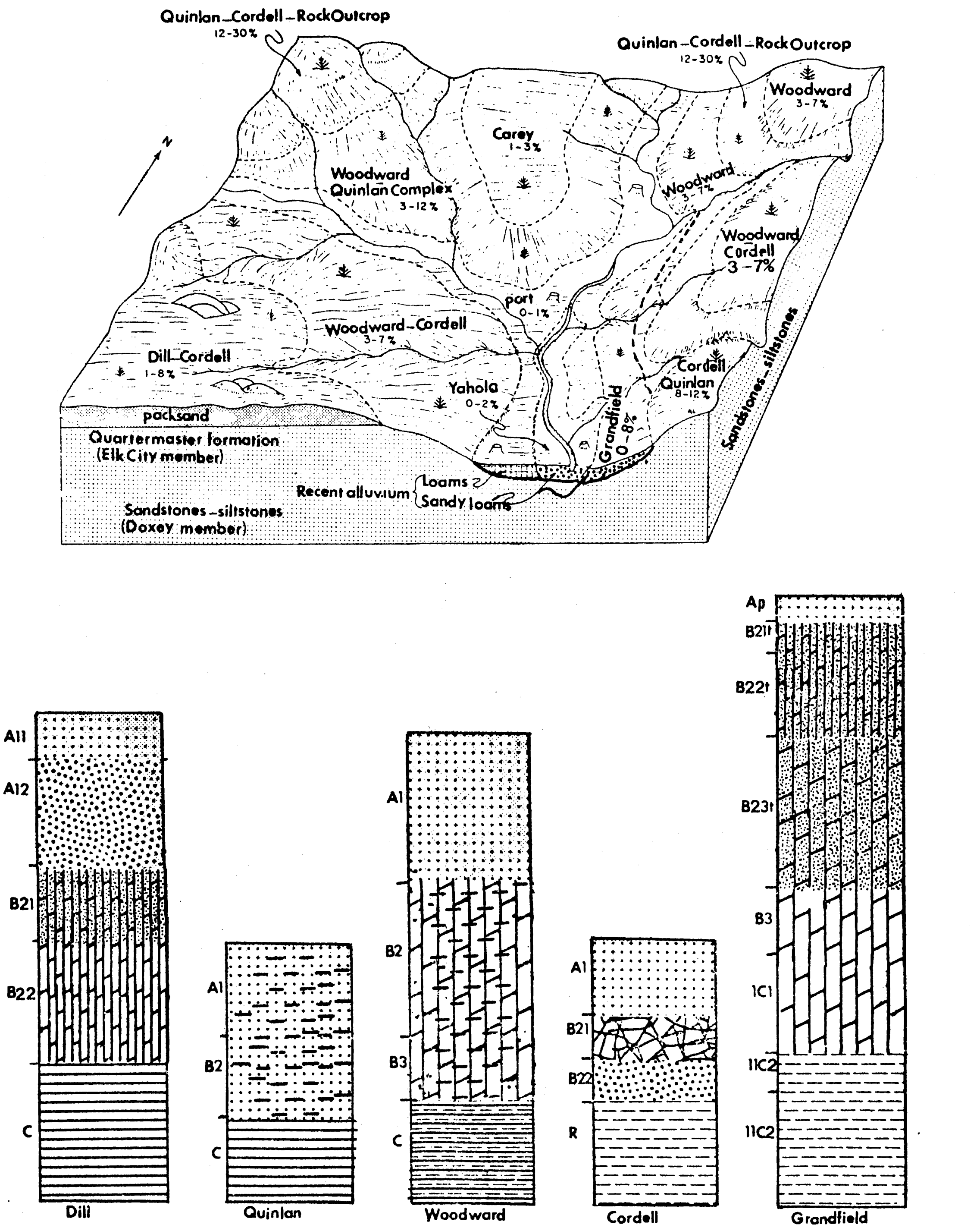

Figure 3. Block diagram showing general landscape of Dill, Quinlan, Woodward, Cordell, Grandfield soils (above) below, two dimensional diagram of the soil profile of the same soils.

CHAPTER III

PROCEDURE

Physical Analysis

Soil samples were air dried under laboratory conditions and processed to pass a 2mm seive. Natural clods were saved for mechanical analyses.

Particles Size Fractionation

$CaCO_3$ removal 40 grams of natural clods were soaked in a 0.5N sodium acetate solution of pH 5 as described by Jackson and modified by the Lincoln Soil Survey Laboratory (12). Soils were soaked for two weeks as suggested by Baktar (11).

Organic Matter Destruction

Organic matter was removed by gradual addition of 31% of hydrogen peroxide. When the organic matter was removed, the color of the soil tended to be bleached.

Soil Dispersion

Soil samples were dispersed by using sodium acetate as a dispersing agent followed by overnight shaking, the dispersion was completed with sonic vibrator for ten minutes.

Soil Separate Measurements

Total clay, fine and coarse silt were measured by the pipette method (2, 29). Sand subfractions were separated using seives no. 20, 40, 60, 140, 270 mesh. Fine clay was determined on the clay remained from particle size analyses. The silt fraction was separated by sedimentation and siphoning. The coarse and the fine clays were separated by the sharpless supercentrifuge.

Chemical Analyses

Organic Matter

Organic carbon was determined by potassium dichromate procedure (Schollenberger 33). Organic matter was calculated by multiplying organic carbon by 1.72

Cation Exchange Capacity

Cation exchange capacity was determined by saturating the samples with sodium acetate solution of pH 8.2, followed by washing with 95% ethanol. Again, the samples were leached with IN ammonium acetate of pH 7. Total sodium in the extract was determined by the atomic absorption spectrophotometer (2).

Extractable Cations

Extractable calcium and potassium, sodium and magnesium were determined by leaching the soil sample three times with ammonium acetate solution at pH 7. Extractable sodium and potassium were measured by atomic absorption spectrophotometer (43). Calcium and magnesium were measured by the Versenate Titration method (8). Exchangeable Al was undertaken by the Titration method (23). Exchanging H determination was according to Peech and et.al. (30).

Base Saturation

Base saturation was calculated by dividing the sum of the NH_4OAC extracted bases by the exchange capacity.

Total Phosphorous

Total phosphorous determination was determined by digesting the soil samples with perchloric acid where molybdcite complex was developed (35).

Soil pH

The soil pH was determined by using the Backman pH meter on a soil-water mixture and on a 1:1 soil-kcl mixture.

Free Iron Oxides

Free iron oxides was measured in both fine and coarse clay remaining after particle size-fractionation. The iron was extracted by the Dithionite-Citrate-bicarbonate method described by Mehra, Jackson, 1960 (25). The iron in the extraction was measured by orthophenanthroline colorimetry method described by Jackson (20).

CHAPTER IV

DISCUSSION

Mechanical Analyses

Cordell Soil

Particle size distribution (Table 1, Figure 4) indicates that A1 and B21 horizons have the highest amount of total clay. The coarse and fine clay decreases with depth. The increase in amount of clay in A1 and B21 is accompanied by a correspondent decrease in amount of both fine and coarse silt. B22 horizon exhibits a transition value between B21 and R layer. Fine/coarse clay ratio indicates a small and unsubstantial change between different horizons, which implies a very low stage of weathering. This is supported by the conversion of small amounts of coarse and fine silt to clay. This is substantiated by the distribution of coarse and fine silt (Table 1) and by change in coarse and very fine sand to fine silt (Table 1) which indicates a gradual decrease of weathering intensity with depth.

Particle size distribution, recalculated to a clay-free basis, shows no significant (Table 1) change between horizons, except a small change in the silt and fine sand fraction in the layer between B22 and the parent material.

TABLE I

MECHANICAL ANALYSES FOR CORDELL SOIL

Particle size distribution for Cordell Soil:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-.5mm	Medium sand 0.5-0.25mm	Fine sand 0.25-.1mm	Very fine sand 0.1-0.05mm	Coarse silt 0.05-0.02mm	Fine silt 0.02-0.002mm	Coarse clay 0.002-0.0001mm	Fine clay <0.0001mm	Ratio fine/coarse clay
A1	0-18	--	<0.1	0.2	0.6	4.9	71.9	4.2	12.0	6.0	0.5
B21	18-28	--	0.3	0.1	0.5	4.0	71.6	4.4	12.3	6.7	0.5
B22	29-36	--	<0.1	0.1	1.0	4.3	79.2	5.2	6.9	3.1	0.4
R	36-63	--	0.3	0.8	1.7	7.2	73.5	6.3	6.6	3.4	0.5

Particle size distribution - recalculated to a clay-free basis:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-0.5mm	Medium sand 0.5-.25mm	Fine sand 0.25-0.1mm	Very fine sand 0.1-0.05mm	Silt 0.05-0.002mm
A1	0-18	--	<0.1	0.2	0.8	5.0	92.9
B21	18-28	--	0.4	0.2	0.7	4.9	93.8
B22	28-36	--	<0.1	0.1	1.1	4.8	93.9
R	36-63	--	0.3	0.8	1.9	8.0	88.7

Ratios of coarse silt and very fine sand to fine silt and the texture class

Horizon	Depth cm	Very fine sand / Fine silt	Coarse silt / Fine silt	Very fine sand + coarse silt / Fine silt	Texture class
A1	0-18	1.2	17.1	22.0	silt loam
B21	18-28	0.9	16.3	20.3	silt loam
B22	28-36	0.8	15.2	19.5	silt
R	36-63	1.1	11.7	18.9	silt

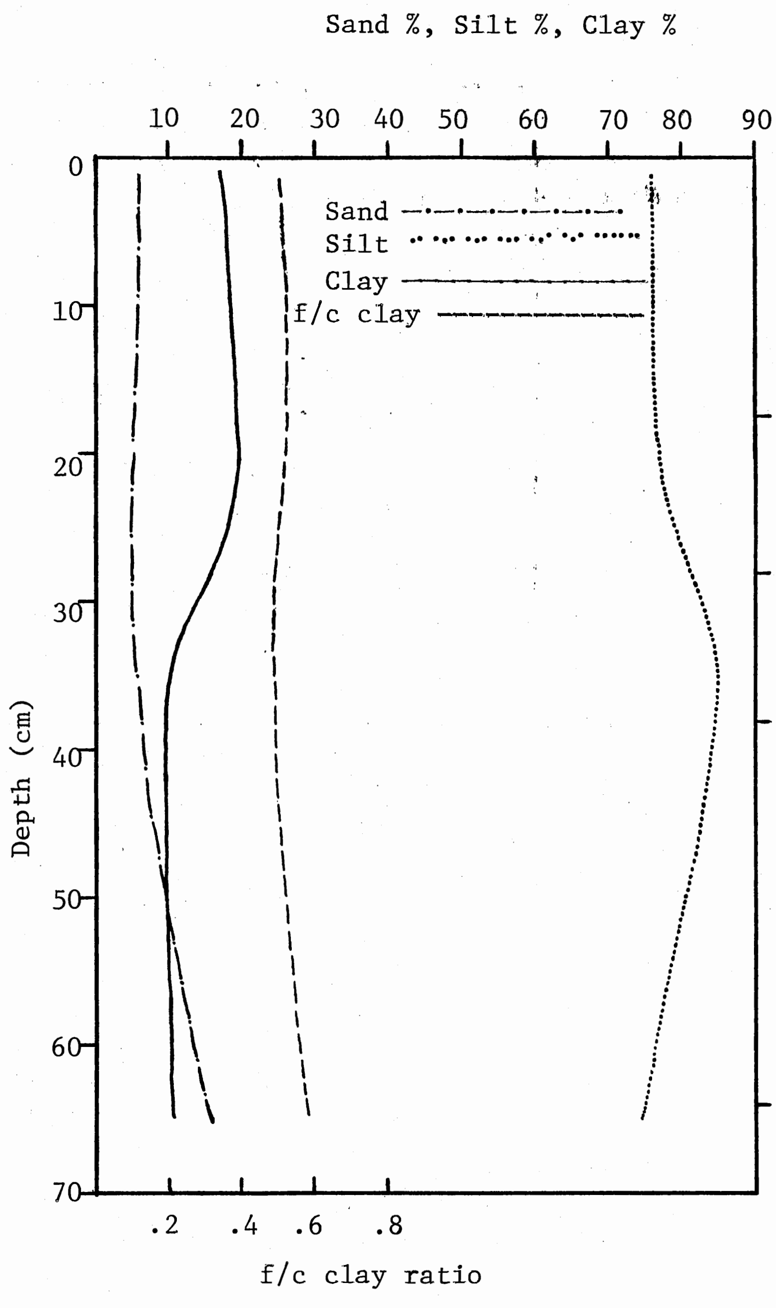

Figure 4. Particle size-depth distribution for Cordell soil.

Quinlan Soil

Particle size analysis shows that clay decreases with depth (Table 2). This change is also accompanied by a gradual decreasing in both fine and coarse clay. Fine/coarse clay ratio for A1 horizon is higher than B horizon. No clay illuviation could be traced from the fine/coarse clay ratio pattern. The fine silt fraction is uniform throughout the profile, coarse clay change sharply between B2 and C horizon. Sand fractions distribution indicates uniform distribution. The sand fraction values recalculated to the free clay basis support this result. The calculated silt (Table 2), very fine, fine sand show a major break between B and C horizon (Figure 5). The only conversion that could be traced in this soil is the relatively small change of coarse and fine silt to clay in the A horizon. This is reflected by higher fine/coarse clay ratio in a horizon over the B2 horizon.

Woodward Soil

Particle-size-depth distribution (Table III, Figure 6) for Woodward soil show an increase in total clay and total silt, but total sand decreases with depth. Total clay and coarse clay fraction increases with depth but fine clay is relatively uniform. Fine clay/coarse clay ratio decreases with depth. The highest ratio is exhibited in A1 horizon followed by B2 and B3 respectively. This indicates that the solum has gained some clay as a result of weathering. No sign of clay illuviation could be traced from the fine/coarse clay ratio. The increase in fine/coarse clay ratio is accompanied by a corresponding decrease in the amount of coarse silt.

The recalculated particle size on a clay-free bases indicates

TABLE II

MECHANICAL ANALYSES FOR QUINLAN SOIL

Particle size distribution for Quinlan soil:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-.5mm	Medium sand 0.5-0.25mm	Fine sand 0.25-.1mm	Very fine sand 0.1-0.05mm	Coarse silt 0.05-0.02mm	Fine silt 0.02-0.002mm	Coarse clay 0.002-0.0001mm	Fine clay <0.0001mm	Ratio fine/coarse clay
A1	0-23	--	<0.1	11	17.3	24.3	34.4	1.4	6.4	5.1	0.8
B2	23-43	--	<0.1	4.4	9.2	35.6	41.1	1.8	5.2	2.6	0.5
C	43-64	--	<0.1	0.1	0.2	23.9	66.5	1.2	3.9	3.4	0.9

Particle size distribution - recalculated to a clay-free basis:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-0.5mm	Medium sand 0.5-.25mm	Fine sand 0.25-0.1mm	Very fine sand 0.1-0.05mm	Silt 0.05-0.002mm
A1	0-23	--	<0.1	12.4	19.5	27.4	40.1
B2	23-43	--	<0.1	4.8	10.0	38.6	46.5
C	43-64	--	<0.1	0.1	0.2	25.8	73.8

Ratios of coarse silt and very fine sand to fine silt and the texture class

Horizon	Depth cm	Very fine sand / Fine silt	Coarse silt / Fine silt	Very fine sand + coarse silt / Fine silt	Texture class
A1	0-23	17.3	24.6	48.9	Loam
B2	23-43	18.8	22.8	58.4	Sandy loam
C	43-64	11.4	31.6	55.5	Loam

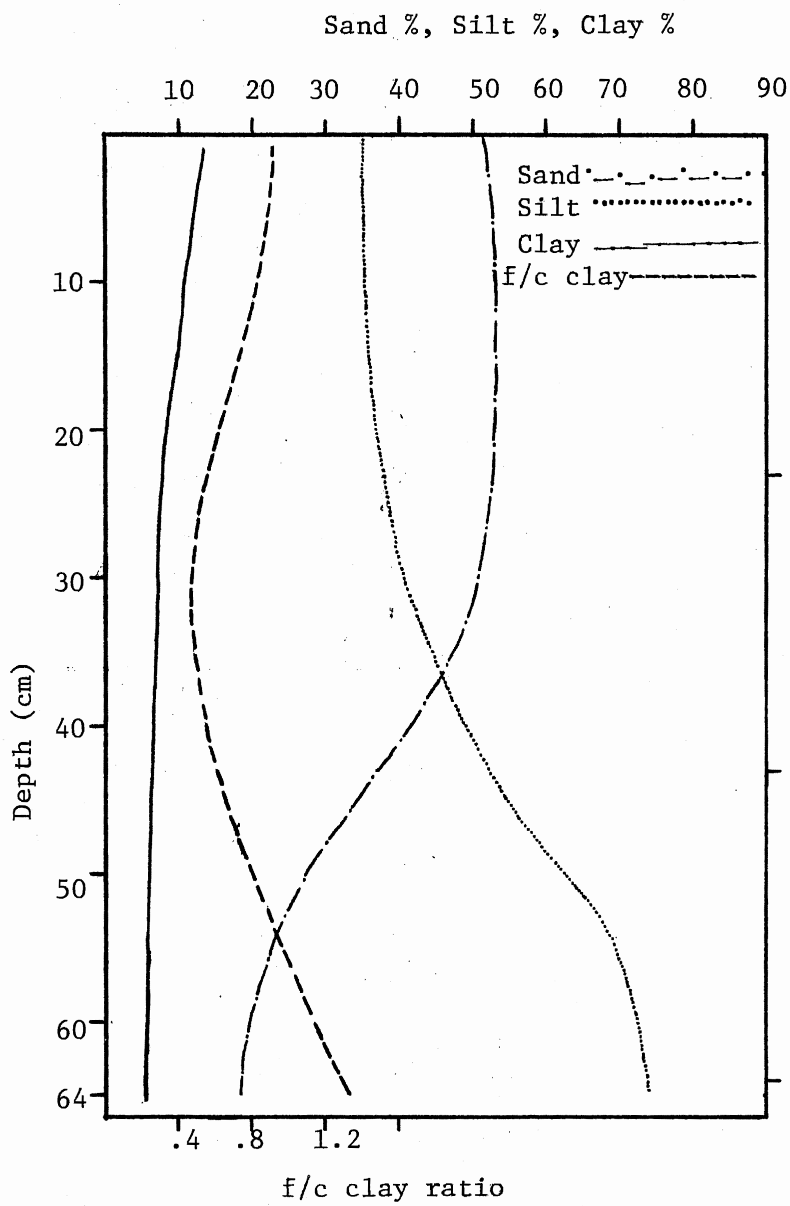

Figure 5. Particle size-depth distribution curve for Quinlan soil.

TABLE III

MECHANICAL ANALYSES FOR WOODWARD SOIL

Particle size distribution for Woodward soil:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-.5mm	Medium sand 0.5-0.25mm	Fine sand 0.25-.1mm	Very fine sand 0.1-0.05mm	Coarse silt 0.05-0.02mm	Fine silt 0.02-0.002mm	Coarse clay 0.002-0.0001mm	Fine clay <0.0001mm	Ratio fine/coarse clay
A1	0- 36	--	<0.1	2.7	4.7	29.5	42.0	5.6	7.8	7.6	1.0
B2	36- 74	--	<0.1	0.5	2.5	30.6	44.7	2.5	9.3	8.8	0.9
B3	74- 89	--	<0.1	0.1	0.7	24.2	51.6	2.6	11.9	8.8	0.7
C	89-114	--	<0.1	0.3	0.5	17.6	54.1	4.3	15.1	8.0	0.5

Particle size distribution - recalculated to a clay-free basis:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-0.5mm	Medium sand 0.5-.25mm	Fine sand 0.25-0.1mm	Very fine sand 0.1-0.05mm	Silt 0.05-0.002mm
A1	0- 36	--	0.1	3.2	5.5	34.9	56.3
B2	36- 74	--	0.1	0.6	3.0	37.4	57.6
B3	74- 89	--	0.1	0.1	0.9	30.5	68.3
C	89-114	--	0.1	0.4	0.6	22.9	75.9

Ratios of coarse silt and very fine sand to fine silt and the texture class

Horizon	Depth cm	Very fine sand / Fine silt	Coarse silt / Fine silt	Very fine sand + coarse silt / Fine silt	Texture class
A1	0- 36	5.3	7.5	37.0	Loam
B2	36- 74	12.2	17.9	48.5	Loam
B3	74- 89	9.3	19.8	44.0	Silt loam
C	89-119	4.1	12.6	30.2	Silt loam

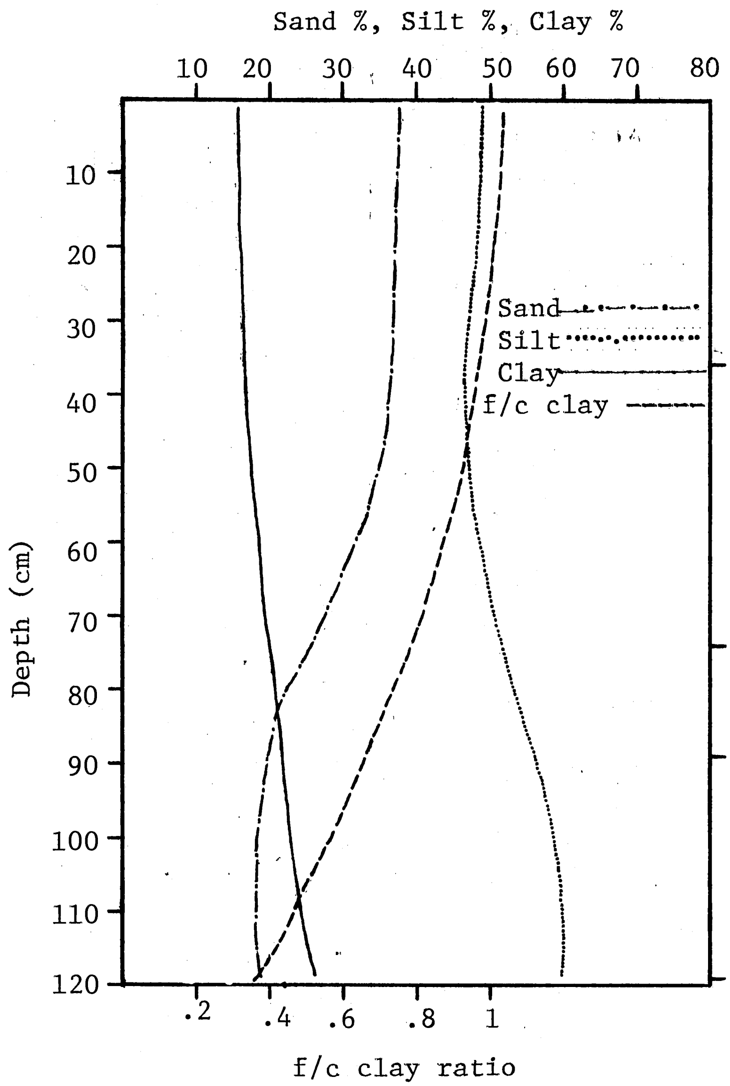

Figure 6. Particle size-depth distribution curve for Woodward soil.

a rather less gradual increase in the silt fraction and less gradual decrease in the very fine and fine sand. This gradual change could be due to the interbedding nature of the parent material which resulted from ununiform sediments. The very fine sand and coarse silt to fine silt (Table III) pronounce a major break between A1 and B or C horizon.

Dill Soil

The particle size distribution (Table 4) shows an increase in the amount of total clay and fine clay in B21 and B22. The total clay increases from 12.6 in all to 17.0 and 16.8 in B21 and B22 respectively. This is accompanied by an increase of the amount of fine clay. Fine/coarse clay suggests that some clay illuviation has occurred, but the amount of total clay change from A12 to B21 and B22 does not qualify the subsoil to build an argillic horizon. The relative high amount of very fine sand and coarse silt with the moderate clay illuviaton suggest that the soil weathering has not proceeded to an advanced stage (Figure 7).

The sudden change in the sand fraction between B22 and C horizon has been investigated by studying the particle size distribution. The subsamples were used to aid this study.

The particle size distribution for subsamples (Table 5, Figure 8) confirms the distribution of the clay in the profile as found by analyzing the major horizons. The B21 horizon and the top part of B22 exhibits the highest amount of fine clay and fine/coarse clay ratio. This confirms the above finding that this soil is on its way to build an argillic horizon. Coarse silt, very fine sand, and medium sand distribution is uniform in the solum. This uniformity is broken at the top of

TABLE IV

MECHANICAL ANALYSES FOR DILL SOIL

Particle size distribution for Dill soil:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-.5mm	Medium sand 0.5-0.25mm	Fine sand 0.25-.1mm	Very fine sand 0.1-0.05mm	Coarse silt 0.05-0.02mm	Fine silt 0.02-0.002m	Coarse clay 0.002-0.0001mm	Fine clay <0.0001mm	Ratio fine/coarse clay
A1	0- 10	--	0.2	6.5	15.6	34.3	29.5	1.2	5.3	7.3	1.4
A12	10- 36	--	0.2	6.6	15.5	33.4	27.8	1.5	6.2	8.7	1.4
B21	36- 53	--	0.3	6.6	15.2	33.7	26.8	1.0	6.4	10.6	1.7
B22	53- 84	--	0.3	5.5	13.0	34.1	29.2	1.1	6.6	10.2	1.5
C	84-119	--	0.3	2.8	2.3	46.6	34.9	0.9	4.8	7.4	1.5

Particle size distribution - recalculated to a clay-free basis:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-0.5mm	Medium sand 0.5-.25mm	Fine sand 0.25-0.1mm	Very fine sand 0.1-0.05mm	Silt 0.05-0.002mm
A1	0- 10	--	0.2	7.4	17.8	39.2	35.1
A12	10- 36	--	0.3	7.7	18.2	39.2	34.4
B21	36- 53	--	0.4	7.9	18.3	40.6	33.5
B22	53- 84	--	0.4	7.8	15.6	41.0	36.4
C	84-119	--	0.3	3.2	2.6	53.1	40.8

Ratios of coarse silt and very fine sand to fine silt and the texture class

Horizon	Depth cm	Very fine sand / Fine silt	Coarse silt / Fine silt	Very fine sand + coarse silt / Fine silt	Texture class
A1	0- 10	28.6	24.6	58.9	Very fine sandy loam
A12	10- 36	22.3	18.5	51.9	Very fine sandy loam
B21	36- 53	33.7	26.8	60.5	Very fine sandy loam
B22	53- 84	31.0	26.5	60.6	Very fine sandy loam
C	84-119	51.8	38.8	86.4	Very fine sandy loam

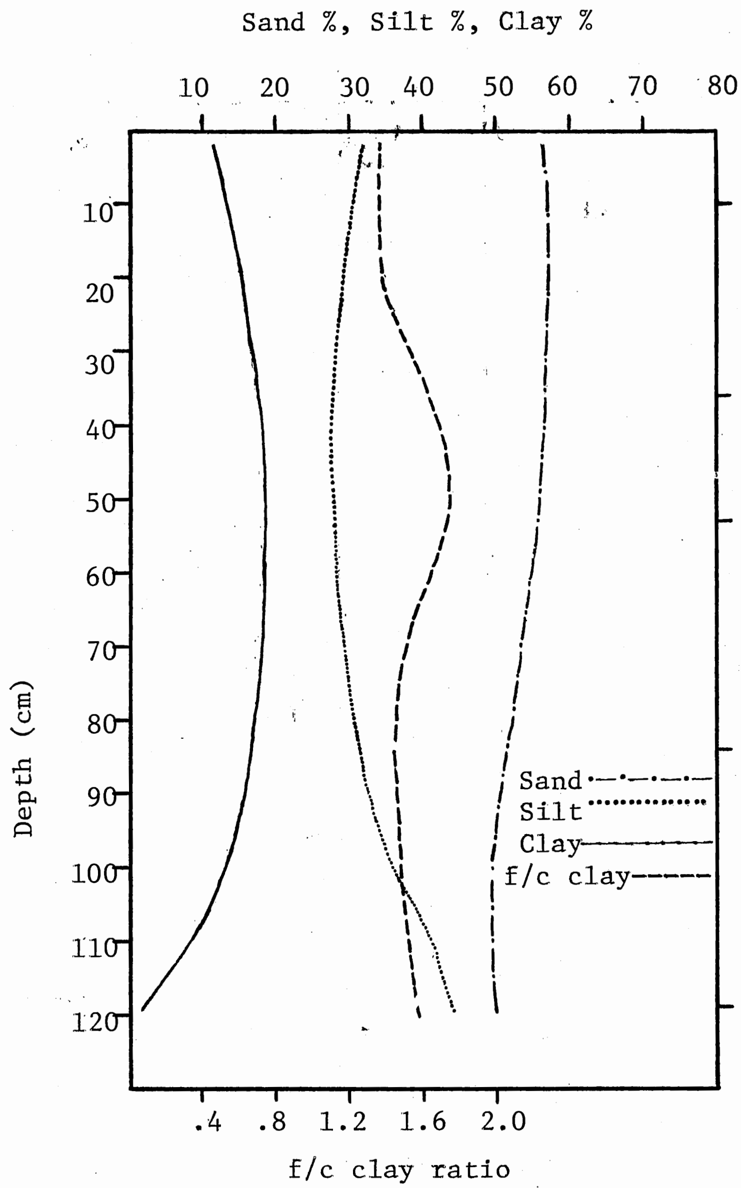

Figure 7. Particle size-depth distribution curve for Dill soil.

TABLE V

MECHANICAL ANALYSES FOR DILL SOIL (SUBHORIZONS)

Particle size distribution for Dill soil (subhorizons):

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-.5mm	Medium sand 0.5-0.25mm	Fine sand 0.25-.1mm	Very fine sand 0.1-0.05mm	Coarse silt 0.05-0.02mm	Fine silt 0.02-0.002m	Coarse clay 0.002-0.0001mm	Fine clay <0.0001mm	Ratio fine/coarse clay
A11	0- 10	--	0.2	6.5	15.6	34.3	29.5	1.2	5.1	7.6	1.5
A12	10- 36	--	0.3	6.6	16.6	35.3	26.7	1.4	6.0	8.4	1.4
B21	36- 53	--	0.2	7.2	13.2	34.3	27.1	1.6	5.8	10.7	1.8
B22	53- 69	--	0.2	6.1	12.2	34.5	29.1	1.6	6.0	10.2	1.7
	69- 76	--	0.2	5.7	10.3	35.8	30.7	1.5	6.3	9.5	1.5
	76- 84	--	0.3	6.4	13.6	42.1	17.7	1.2	7.9	10.8	1.4
C1	84- 94	--	0.1	0.8	0.2	47.6	34.4	1.5	7.7	7.7	1.0
C2	94-119	--	0.1	0.3	0.3	54.0	33.4	1.5	6.7	4.7	0.7

Particle size distribution - recalculated to a clay-free basis:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-0.5mm	Medium sand 0.5-.25mm	Fine sand 0.25-0.1mm	Very fine sand 0.1-0.05mm	Silt 0.05-0.002mm
A11	0- 10	--	0.2	7.4	17.9	39.3	35.1
A12	10- 36	--	3.0	7.7	18.2	41.2	32.8
B21	36- 53	--	0.2	8.6	15.8	41.1	34.4
B22	53- 69	--	0.2	7.4	14.5	41.2	36.7
	69- 76	--	0.2	6.7	12.3	42.5	38.2
	76- 84	--	0.4	7.9	16.7	51.8	23.0
C1	84- 94	--	0.1	0.9	0.2	56.3	42.4
C2	94-119	--	0.1	0.4	0.3	60.9	39.4

Ratios of coarse silt and very fine sand to fine silt and the texture class

Horizon	Depth cm	Very fine sand / Fine silt	Coarse silt / Fine silt	Very fine sand + coarse silt / Fine silt	Texture class
A11	0- 10	29.6	24.6	58.9	Very fine sandy loam
A12	10- 36	26.2	19.1	54.4	Very fine sandy loam
B21	36- 53	21.4	16.9	51.2	Very fine sandy loam
B22	53- 69	21.6	18.3	52.7	Very fine sandy loam
	69- 76	23.9	20.5	56.3	Very fine sandy loam
	76- 84	35.1	14.7	56.8	Very fine sandy loam
C1	84- 94	31.7	22.9	70.5	Loam
C2	94-119	36.0	22.3	76.3	Very fine sandy loam

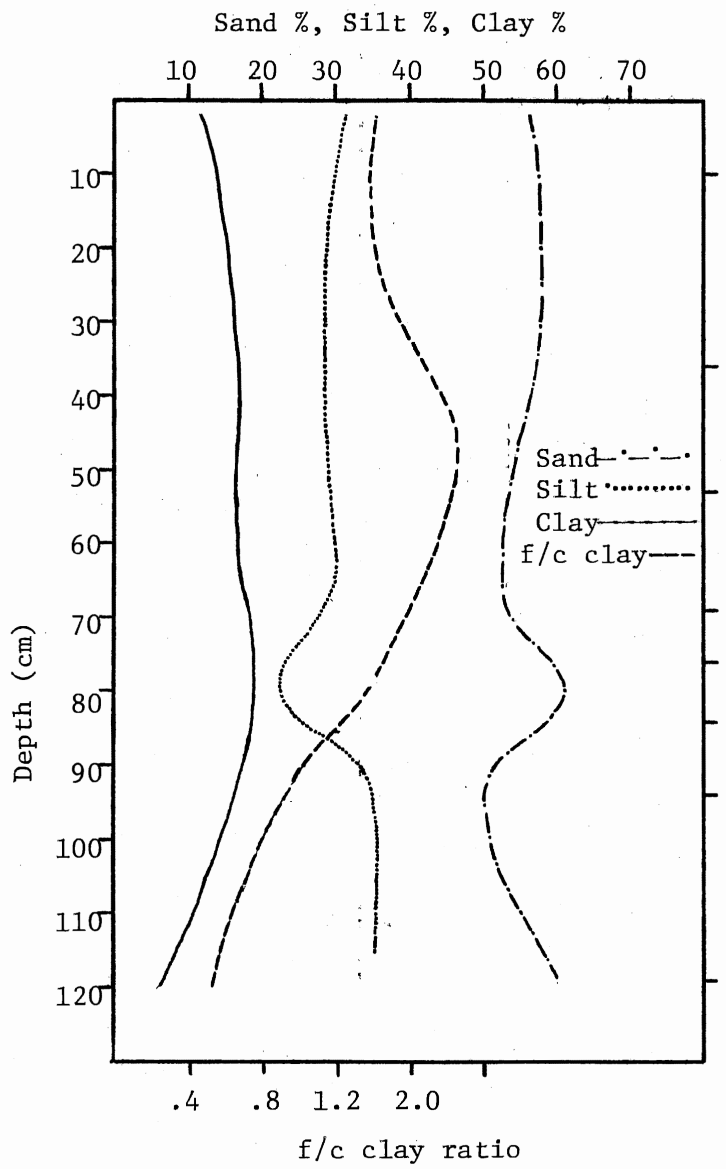

Figure 8. Particle size-depth distribution curve for Dill soil (subsampled horizon.

the C horizon by a sudden change in the value for these fraction. The particle size distribution, recalculated to a clay-free basis, suggests a stratification in the parent material (Table IV). The ratios of coarse silt and very fine sand to fine sand (Table IV) show that the silt in the solum has been weathered to clay.

Grandfield Soil

Table VI shows the particle size distribution. Figure 9 shows the distribution of total clay, total silt, sand, and fine/coarse clay ratio. These data indicate the sandy skeletal nature of this soil. Maximum clay accumulation occur between 18 and 122 cm. Fine/coarse clay ratio change from 1.2 in Ap to 1.8 in B21t, B22t and B23t, indicating that clay illuviation has started in this soil. The clay content and the fine/coarse clay of subsoil indicate the presence of argillic horizon (Soil Toxonomy, 38). Below 122 cm both clay and silt decrease up to 203 cm then increase sharply below 203 cm supporting the unconformity nature of the last two horizons. The values of recalculated particle size on free clay bases also provide another evidence on the unconformity nature of the last two horizon (Table VI).

Ratio of very fine sand/fine silt, coarse/fine silt and very fine sand + coarse silt/fine sand for Ap horizon (Table VI) shows that the fine silt fraction has been lost. This possibly could happen by mechanical translocation through soil cracks or by wind deflation.

Chemical Analyses

Organic Matter

Tables VII and VIII show the distribution of organic matter in all

TABLE VI

MECHANICAL ANALYSES FOR GRANDFIELD SOIL

Particle size distribution for Grandfield soil:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-.5mm	Medium sand 0.5-0.25mm	Fine sand 0.25-.1mm	Very fine sand 0.1-0.05mm	Coarse silt 0.05-0.02mm	Fine silt 0.02-0.002m	Coarse clay 0.002-0.0001mm	Fine clay <0.0001mm	Ratio fine/coarse clay
AP	0- 18	--	0.5	11.2	42.5	18.9	14.6	0.2	5.5	6.5	1.2
B21t	18- 33	--	0.3	12.1	41.3	13.5	13.1	1.2	6.5	11.9	1.8
B22t	33- 76	--	0.1	9.5	36.8	20.3	13.1	2.3	6.4	11.5	1.8
B23t	76-122	--	0.4	11.7	41.8	20.6	8.6	0.7	5.8	10.2	1.8
B3	122-155	--	0.4	17.4	41.6	22.0	7.5	0.6	4.3	5.1	1.2
IC1	155-203	--	0.1	22.0	46.3	18.1	6.7	1.3	2.7	2.8	1.0
IIC1	203-221	--	2.7	14.3	37.4	16.1	6.6	2.3	12.7	8.2	0.7
IIC2	221-279	--	1.1	1.1	4.7	10.9	35.7	14.6	19.6	12.3	0.5

Particle size distribution - recalculated to a clay-free basis:

Horizon	Depth cm	Very coarse sand 2-1mm	Coarse sand 1-0.5mm	Medium sand 0.5-.25mm	Fine sand 0.25-0.1mm	Very fine sand 0.1-0.05mm	Silt 0.05-0.002mm
AP	0- 18	--	0.5	12.7	48.3	21.5	16.8
B21t	18- 33	--	0.4	14.9	50.6	16.6	17.5
B22t	33- 76	--	0.1	15.6	44.8	24.7	18.8
B23t	76-122	--	0.5	14.0	40.8	24.6	11.1
B3	122-155	--	0.5	19.2	47.1	24.4	8.9
IC1	155-203	--	<0.1	23.2	49.0	19.2	8.5
IIC1	203-221	--	3.4	18.0	47.1	19.0	11.2
IIC2	221-279	--	1.6	1.6	7.1	15.9	73.8

Ratios of coarse silt and very fine sand to fine silt and the texture class

Horizon	Depth cm	Very fine sand / Fine silt	Coarse silt / Fine silt	Very fine sand + coarse silt / Fine silt	Texture class
AP	0- 18	94.5	73.0	91.9	Fine sandy loam
B21t	18- 33	11.2	10.9	24.4	Fine sandy loam
B22t	33- 76	8.8	5.7	26.0	Fine sandy loam
B23t	76-122	29.4	12.3	32.9	Fine sandy loam
B3	122-155	36.7	12.5	34.5	Fine sandy loam
IC1	155-203	13.9	5.1	23.2	Fine sandy loam
IIC1	203-221	7.0	2.9	19.0	Fine sandy loam
IIC2	221-279	0.7	2.4	13.3	Fine sandy loam

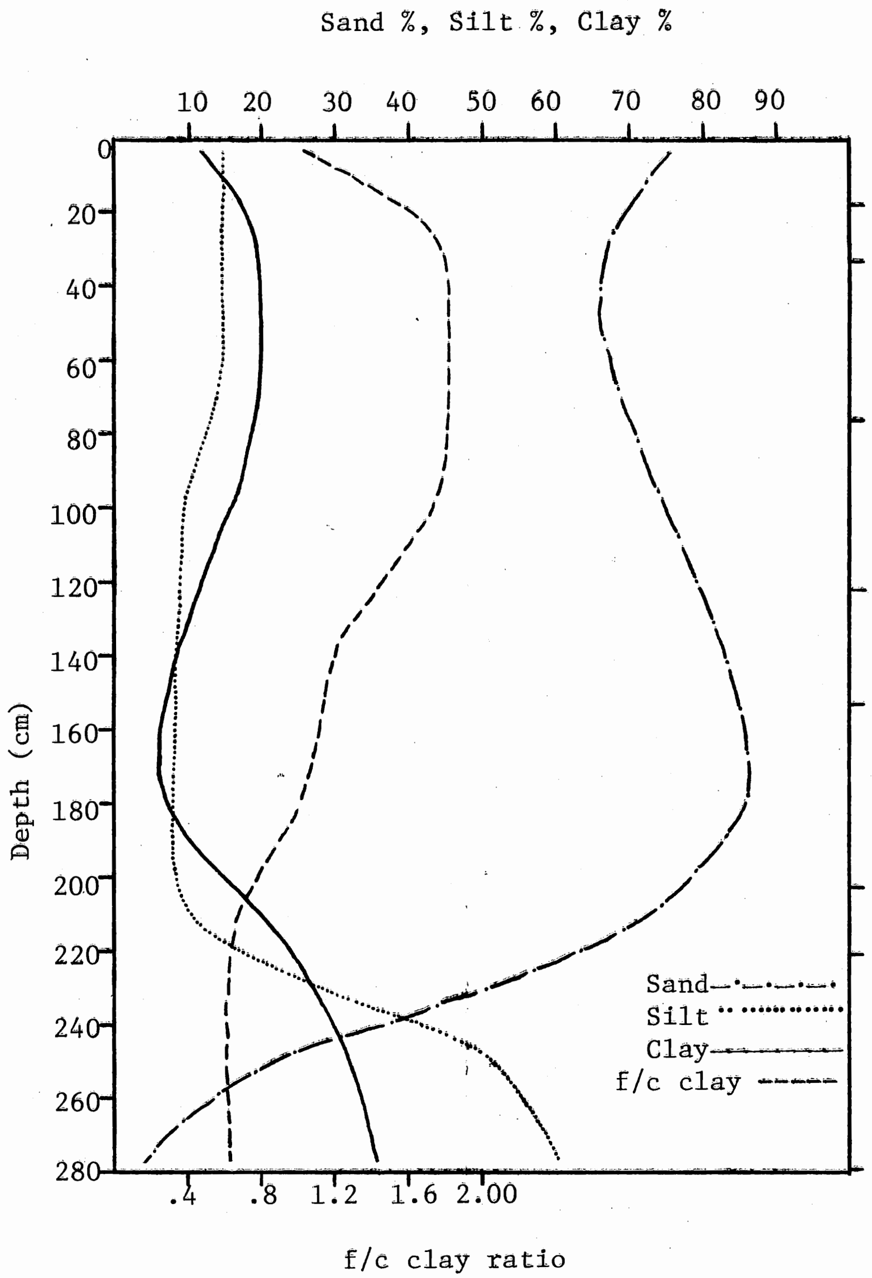

Figure 9. Particle size-depth distribution for Grandfield soil.

five pedons studied. The value of organic matter shows the effect of grass on these soil, where the surface soil maintains the highest organic matter content with a gradual decline of organic matter with depth. The soils studied do not exhibit any accumulation or organic matter in deeper layers. The organic matter content of different horizon exhibit a gradual change between A and B horizon and a rather sharp change between B and C horizon. Grandfield soil shows another pattern where the organic matter decreases from .99% in B22t to .54% in B23t also shows a gradual change between B and C horizon.

The average organic matter content of upper 50 cm of each epipedon studied has greater than one percent organic matter required for a mollic epipedon. Nevertheless, due to lack of dark layer thickness, or the development of soft consistency, none of these soils will be allowed to have mollic epipedon as required by soil taxonomy (40).

Calcium Carbonate

Calcium carbonate percent for the five soils is shown in Tables 7 and 8. The laboratory date shows that each soil exhibits different stage of calcium carbonate leaching.

Cordell Soil

In this soil, the calcium carbonate is slightly removed from A1 and to a lesser extent from B21. No secondary calcium carbonate occurs in this soil.

Quinlan Soil

This soil has a little advanced leaching stage than Cordell soil.

TABLE VII

CHEMICAL ANALYSES OF WOODWARD, CORDELL AND DILL SOIL

Depth cm	Field desig- nation	pH H_2O	1:1 KCL	CEC meg/ 100 gms.	Extractable cat. meg/100gms. H+	Ca^{+2}	Mg^{+2}	K+	Na+	AL^{+3}	Base saturation NaAc	sum of cation	Ca/Mg	CEC/clay	Total p p.p.m/ 100 gms
							---------Woodward Soil---------								
0- 36	A	7.55	7.5	9.4	5.12	14.07	3.82	0.42	0.09	0.00	100.0	78.2	3.68	62.67	337.4
36- 74	B_2	7.90	7.9	6.8	1.14	32.72	4.28	0.23	0.09	0.00	100.0	97.0	7.64	42.33	396.9
74- 89	B_3	8.00	7.8	5.7	1.14	31.54	4.80	0.19	0.09	0.00	100.0	97.0	6.59	33.93	476.2
89-114	C	8.10	8.1	5.0	2.84	29.98	6.20	0.19	0.09	0.00	100.0	92.6	4.69	27.17	416.7
							----------Cordell Soil---------								
0- 18	A	7.60	7.1	19.0	7.11	29.11	5.54	0.64	0.o9	0.00	100.0	83.3	5.25	105.26	446.5
18- 28	B_{21}	7.86	7.5	18.6	5.12	36.11	5.38	0.44	0.09	0.00	100.0	89.3	6.84	97.84	456.4
28- 38	B_{22}	7.90	7.8	15.7	4.55	36.46	6.01	0.33	0.17	0.00	100.0	90.4	6.07	155.90	535.8
38- 64	R	8.20	7.9	11.7	3.98	34.10	6.97	0.30	0.17	0.00	100.0	91.3	4.89	116.53	456.4
							-----------Dill Soil----------								
0- 10	A_{11}	6.50	6.2	13.7	1.70	8.00	3.44	0.60	0.10	0.00	82.1	87.6	2.32	116.67	228.2
10- 36	A_{12}	6.40	5.8	12.9	0.80	7.10	2.94	0.40	0.10	0.00	81.3	92.6	2.41	86.93	158.8
36- 53	B_{21}	6.50	5.9	14.4	0.80	8.10	3.83	0.20	0.10	0.00	84.3	93.5	2.14	84.85	163.7
53- 84	B_{22}	7.50	6.0	14.7	1.10	8.80	4.03	0.20	0.10	0.00	85.9	91.7	2.05	87.24	193.5
84-119	C	8.30	7.6	12.6	0.00	29.10	5.04	0.10	0.10	0.00	100.0	100.0	5.87	121.15	352.7

TABLE VIII

CHEMICAL ANALYSES OF GRANDFIELD AND QUINLAN SOILS

Depth cm	Field designation	pH H_2O	1:1 KCL	CEC mg/ 100 gms	Extractable cat. meq/100 gms H+	Ca^{+2}	Mg^{+2}	K+	Na+	AL^{+3}	Base saturation NaAc	Sum of cation	Ca/mg	CEC/Clay	Total p ppm/ 100 gms
							--------Grandfield Soil--------								
0- 18	AP	5.55	6.3	9.5	1.14	5.67	1.64	0.41	0.11	0.00	82.5	87.3	3.46	79.03	103.2
18- 33	B21t	6.35	6.1	13.4	1.42	6.93	2.73	0.43	0.09	0.00	76.0	87.7	2.54	72.74	99.3
33- 76	B22t	6.00	5.7	14.2	3.13	6.85	3.78	0.23	0.11	0.00	77.3	77.8	1.81	79.66	84.4
76-122	B23t	5.80	5.0	10.8	1.71	5.04	3.11	0.17	0.13	0.00	78.3	83.2	1.62	67.20	79.4
122-155	IB3	6.00	5.3	6.7	0.85	3.02	2.35	0.15	0.15	0.00	85.3	86.9	1.29	70.67	49.7
155-203	IC1	6.25	5.6	3.7	0.07	1.85	1.22	0.09	0.13	0.00	87.9	85.3	1.52	66.66	29.8
203-221	IIC1	6.50	6.0	18.6	2.60	6.95	3.77	0.29	0.26	0.00	60.2	81.4	1.84	90.12	102.5
221-279	IIC2	7.60	6.5	32.3	2.30	22.72	6.57	0.43	0.41	0.00	90.2	92.9	3.46	84.66	312.5
							---------Quinlan Soil----------								
0- 23	A1	7.75	7.5	10.3	2.29	27.55	3.40	0.33	0.09	0.00	100.0	93.2	8.10	93.63	369.1
23- 43	B2	7.95	7.8	8.0	0.00	31.29	3.23	0.21	0.09	0.00	100.0	100.0	9.68	118.50	431.6
43- 64	C	8.10	7.8	6.4	1.15	29.90	3.61	0.15	0.09	0.00	100.0	96.7	8.28	100.31	471.6

The distribution of calcium carbonate indicates a maximum leaching from the Al horizon and a secondary accumulation in the B horizon. Calcium carbonate content in A horizon is 4.3% and increases to 14.8% in B horizon then decreases to 12.45% in C horizon. No secondary calcium carbonate could be seen in the soil profile as the result of this amount of leaching.

Woodward Soil

The distribution of calcium carbonate exhibits more leaching than Quinlan and Cordell soil. The laboratory data indicates that B2 is next to A horizon which is the most leached layer. The amount of $CaCO_3$ percentage changes from 2.7% in A horizon to 15.6 and 19.55 in B2 and B3 respectively. Very little change occurs in the amount of calcium carbonate removed from the B3 in relation to the C horizon. Very few films of soft secondary calcium carbonate start showing in the lower part of the B3 horizon which reflects the extent of the amount and the depth of carbonate leaching in this soil.

Dill Soil

The calcium carbonate distribution for this soil indicates that this soil is more leached than any of the other soils. Calcium carbonate content in the solum is rather constant and increases drastically in the C horizon. The carbonate content range from 1% in the surface horizon to 1.2% in the lower part of the solum. Few films of secondary soft calcium carbonates occur in B21 and B22.

TABLE IX

ORGANIC MATTER, $CaCO_3$ AND FREE IRON OXIDES

IN FINE AND COARSE CLAY

Horizon	Depth cm	OM%	$CaCO_3$%/ 100 mg of soil	Free iron% in fine clay	Free iron% in coarse clay
		--Cordell Soil--			
A1	0- 18	2.16	1.69	1.53	12.61
B21	18- 28	1.92	1.72	3.06	11.99
B22	28- 36	1.42	2.00	1.05	6.33
R	36- 64	0.09	2.50	0.45	6.32
		--Quinlan Soil--			
A1	0- 23	1.71	4.30	3.08	5.08
B2	23- 43	1.54	14.82	0.94	5.55
C	43- 64	0.61	12.45	1.02	3.82
		--Woodward Soil--			
A1	0- 36	2.13	2.70	3.17	4.58
B2	36- 74	1.13	15.60	3.29	6.41
B3	74- 89	0.91	19.55	5.80	8.62
C	89-114	0.69	20.62	2.68	12.16
		--Dill Soil--			
A11	0- 10	1.96	1.00	3.42	4.17
A12	10- 36	1.26	0.92	5.00	5.57
B21	36- 53	0.99	1.10	4.98	5.04
B22	53- 84	0.90	1.20	4.75	7.89
C	84-119	0.15	14.85	5.55	9.16
		--Grandfield Soil--			
AP	0- 18	1.00	0.33	2.14	3.53
B21t	18- 33	1.14	0.66	5.14	6.83
B22t	33- 76	0.99	0.66	5.19	5.12
B23t	76-122	0.54	0.33	5.13	5.19
B3	122-155	0.35	0.33	3.80	3.79
IC1	155-203	0.08	0.40	1.73	2.34
IIC2	203-279	0.09	0.85	9.26	16.90

Grandfield Soil

Grandfield soil developed from alluvial material reworked by wind. The sandy nature of this soil provides a good path for the percolation of water through the profile. The calcium carbonate content of this soil is very low and very uniform throughout the profile except a little accumulation of this material in the B21t and B22t. It seems that the limited amount of calcium carbonate in the profile did not prohibit the movement of the small amount of clay required for argillic horizon.

More detailed study of calcium carbonate distribution conducted on subsamples is presented in another chapter.

pH and Base Saturation

Cordell Soil

Table 7 shows the pH value-depth distribution pH value change from 7.55 in the A horizon to 7.9 in the B3 to 8.2 in the C horizon. The pH increases as the calcium carbonate content increases. These values indicate low degree of the solum leaching above the C horizon. The pH determined by 1:1 kcl differ slightly from the 1:1 H_2O method. This indicates that the Al is significantly absent on the exchange site as substantiated by Al determination. The base saturation by summation of cation indicates a very small loss of cations from the A horizon.

Quinlan Soil

pH values for this soil indicate a slight change between the solum and the parent material. The pH value increased slightly between the A and the B horizon. The increase in pH value is accompanied by the accumulation of calcium carbonate in the lower part of B horizon.

The kcl 1:1 pH value differ slightly from its 1:1 water counterpart indicating the absence of Al on the exchange sites of the soil. This subatantiated by Al determination which average to zero in the solum and the parent material.

The base saturation by the ammonium acetate method shows no difference between different horizons. The base saturation by summation of cations, the exchangeable value of different cations, and hydrogen suggest that leaching processes has started in this soil.

Woodward Soil

pH value increases slightly from A to C horizon. The pH values change from 7.55 in A horizon to 8.1 in the C horizon. At the same time $CaCO_3$ content increases from 2.7% in A horizon to 20.62% in the C horizon. The base saturation by cation summation is the lowest in the A horizon and highest in the C horizon. The kcl 1:1 pH and Al measurement indicates the absence of this element on the exchange site. The moderate change in base saturation indicates the leaching is concentrated at the top of the soil and decreases rapidly with depth.

Dill Soil

The pH value for this soil indicates the slightly acid nature of solum. pH value varies from 6.5 in the surface horizon to 8.3 in the C horizon. The pH depth distribution pattern follows closely the change of the calcium carbonate change which indicates that the whole solum has been subjected to intensive leaching. Base saturation behaves similarly to pH and calcium carbonate. All these measurements show a sharp increase between the solum and the C horizon; they also provide a good indication of the depth of the soil leaching.

The 1:1 kcl pH determination is lower, .65 to .35 units from its 1:1 water component. Nevertheless, Al is still absent on the exchange sites.

Grandfield Soil

Table 8 shows the pH values for major horizons of Grandfield. The pH values indicates that this soil is acidic in reactions. A horizon is more acidic than B horizon. No major change occurs between the different horizons which indicates the acidic nature throughout the profile. The unrelated layers exhibited a rather higher pH value. The pattern of pH-value change is identical of the calcium carbonates which is equally distributed between the different horizons.

The base saturation values of this soil reveal the leaching status of this soil. The equality of the base saturation throughout the profile proposes two cases: first, either weak leaching, which suggests that this soil is originally low in exchangeable cations; or second, the soil has been intensively leached throughout the profile. The pH 1:1 kcl value and Al measurement also indicates the absence of Al on the exchange site of the soil.

Extractable Cations and Ca/mg Ratio

The extractable cations data indicates that the calcium cation is dominant in all soil. The highest amount of calcium on the exchange site is found in Cordell soil and to a less degree in Quinlan soil. Grandfield maintains the least amount of exchangeable calcium. In all soil, exchangeable calcium distribution indicates movement of this cations from the A horizon to the subsoil. Extractable cations data also suggests that mg is next dominant to calcium. These data also show no or very little evidence of mg movement in the profile.

In recent years, an attempt has been made to use the ca/mg ratio as another criteria for characterization of soil and studying the movement of calcium and magnesium as a function of soil weathering.

The ca/mg ratio distribution for Cordell soil shows that ca movement from the surface horizon to the subsoil has taken place in this soil. The same relationship exists from Quinlan soil. In Woodward soil, the vertical distribution of ca/mg indicates that A horizon has 3.68 and 7.64, 6.59 for B2 and B3 respectively. This suggests more intensive Ca movement in Woodward than Quainland and Cordell especially from the surface horizon.

The ca/mg ratio is uniform in the solum of Dill soil. It ranges from 2.32 in AII horizon to 2.05 in B22 and 5.87 in C horizon. This suggests that the whole solum has been uniformly leached.

In Grandfield, Ap horizon has the highest ca/mg ratio. The vertical distribution exhibits a decrease with depth. Through extractable calcium distribution shows some movement between different horizon, but ca/mg reveals no Ca movement in relation to mg in the profile.

Cation Exchange Capacity Measurement

Soil pedons in this study show a low cation exchange capacity for all horizons. The exchange capacity for all pedons shows some correlation with clay percentage and better relationships with the distribution of fine clay.

In Cordell soil, A1 horizon has the maximum CEC value followed by B21 horizon. This coincides with the amount of clay for each horizon. A slight increase in the CEC/clay in A horizon over B21 could be due to the effect of organic matter.

CEC values for Quinlan soil indicates that A horizon has the highest CEC value. CEC changes from 10.3 in A horizon to 6.4 in the C horizon. The CEC of the soil increases directly in proportion to the percent of clay. The horizon with highest CEC have the highest percent of fine and total clay. The slight difference in CEC values indicates the weathering status of this soil.

In Woodward soil, the CEC-depth distribution gives a close relationship with fine-clay depth distribution. Particle size analyses indicates that coarse clay increases with depth, but the fine clay fraction distribution is uniform with depth. CEC measurement for this soil maintains maximum value at the surface horizon and decreases with depth. This substantiates the conclusion reached through particle size distribution which suggests that the increase in the total clay with depth is a result of interbedding, but the uniform distribution of fine clay, the decrease in final coarse values, and the decrease in the CEC values have resulted from the soil formation processes.

In Dill soil, the B21 and B22 maintain the highest CEC value. The CEC is 13.7 for A11 and drops to 12.9 in A12. Then it increases to 14.4 and 18.7 in B21 and B22. It appears that the slight accumulation of fine clay in the subsoil is responsible for the difference in the CEC between A and B horizon. The CEC (100 gm of clay) for A11 horizon is slightly higher than other horizons in the solum. This could be due to the organic matter effect.

The CEC for Grandfield indicates that the argillic horizon has the highest CEC values (Table 8). The CEC value-depth distribution shows a close relation to the distribution of the fine clay distribution in the profile. Ap horizon which lost some of its fine clay has CEC of 9.5 while the argillic horizon has 13.4, 14.2 and 10.8. This variation is identical of the fine clay distribution. The exchange capacity (per 100 gm of clay) for Ap horizon is higher than those for the underlying horizons. This is partly due to the organic matter effect.

Free Iron

Table 9 shows the distribution of free iron oxides in both the coarse and fine clay. In Cordell soil the coarse clay fraction contains higher amounts of free iron oxides than does the fine clay. The amount of free iron in the coarse clay decreases from 12.61% in A1 to 6.32 in C horizon, whereas the free iron oxides change from 1.53% to .45% in the fine clay fraction for the same horizon. This indicates that most of the weathering occurred in the coarse fraction at the surface horizon. (Figure 10) shows the relationship between fine and coarse clay and the free iron oxides.

Free iron distribution in Quinlan soil (Figure 11) also show the same relationship between free iron and both fine and coarse clay. In both soils, layers of maximum free iron content have undergone most intensive leaching.

The data for Woodward soil indicate that coarse clay increases with depth and so does the amount of free iron (Figure 12), but the fine clay and its free iron content shows a rather uniform distribution. At the same time, the coarse fraciton does contain higher amounts of free iron oxide of the coarse clay increases gradually with depth, but the free iron oxide of the fine clay is relatively constant with depth.

In Grandfield (Figure 14), the fine clay has almost the same amount of fine clay as does the coarse clay especially in the argillic horizon. The distribution of free iron oxides closely resembles that of fine and coarse clay. This might suggest a close relationship between fine clay and iron accumulation in the profile. The relationship between fine clay and free iron oxides increases from Cordell to Quinlan, Woodward, Dill and Grandfield respectively. The increase of free iron amounts in the fine clay fraction could be interpreted indicating that as weathering proceeds, there is a shift of iron within a horizon from the coarse clay fraction to the fine clay fraction. The sequence of the increase in the amount of free iron oxides from Cordell in one side, which represents the least weathering soil, to Grandfield, which represents the highest weathering soil, could be substantiated on the basis of particle size, intensity of carbonate leaching, base saturation and pH values.

Podzolization is defined as that process (or processes) by which soil are depleted of bases, become acid, had developed eluvial horizon, and illuvial B horizon without stating the degree or the form. The accumulation of considerable free iron oxides in the B horizon is interpreted as an indication of the podzolization processes. Holding this view, in Grandfield, where Bt horizon contains the highest amount of free iron oxides in both the coarse clay fraction, the lowest base saturation and the lowest pH values, it would be appropriate to consider that podzolization processes has began in this soil. This would put Grandfield in a stage ahead of the other soils.

No relationship exists between the color of the soil and the free iron oxides content. It is observed that the parent material of Cordell soil, with the lowest amount of free iron in both clay fractions, is as red as the surface horizon. Furthermore, parent material of Dill soil is less red than the surface or sub-surface horizon even though it contains higher amounts of free iron. This might suggest that other soil fractions are responsible for soil color reddening or, that soil fractions had been lost from the upper profile during the processes of soil formation. The finer fractions possibly suffer the greatest loss. The loss could be by water erosion or wind deflation.

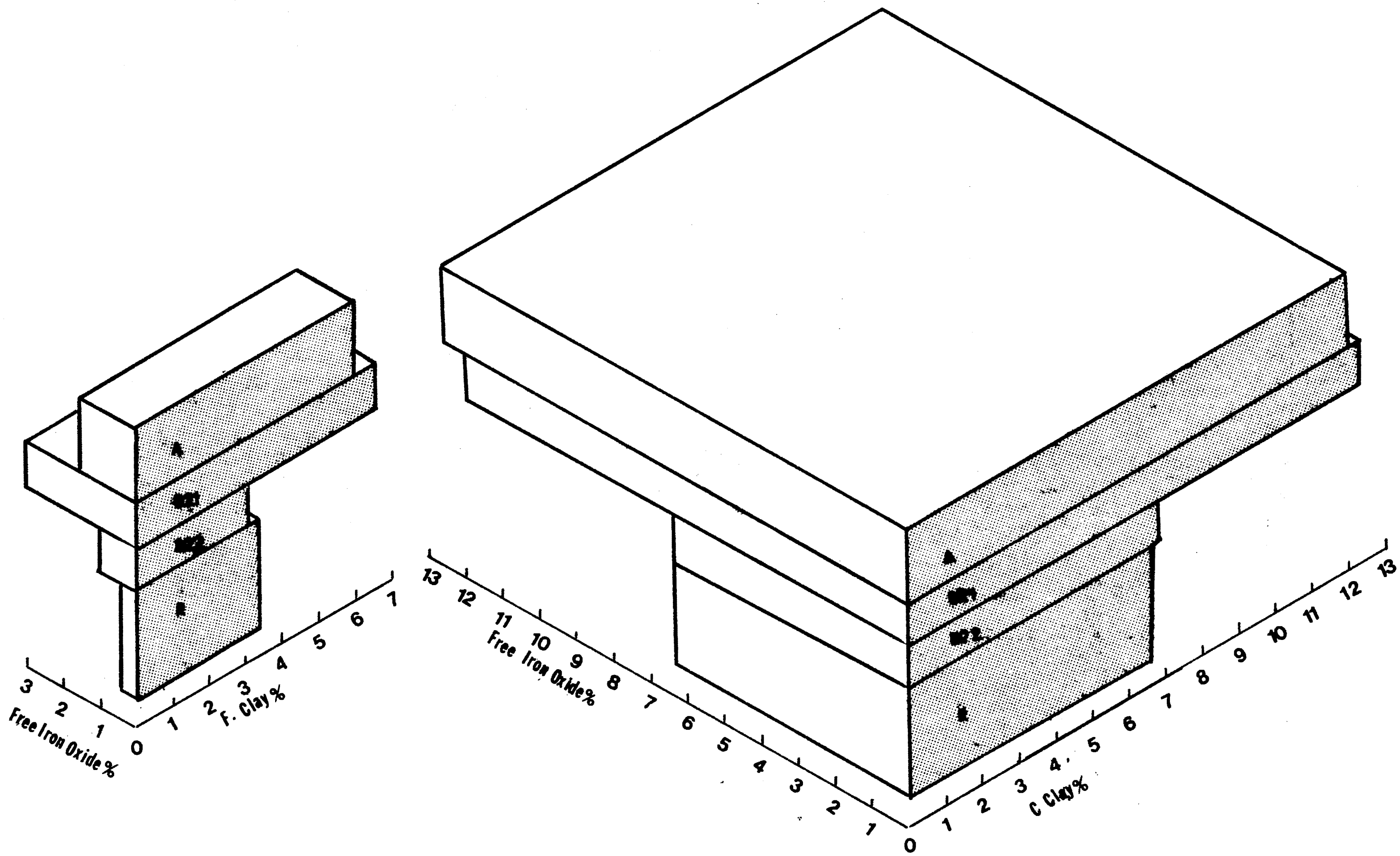

Figure 10. Free iron oxides percentage for the fine and the coarse clay for Cordell soil.

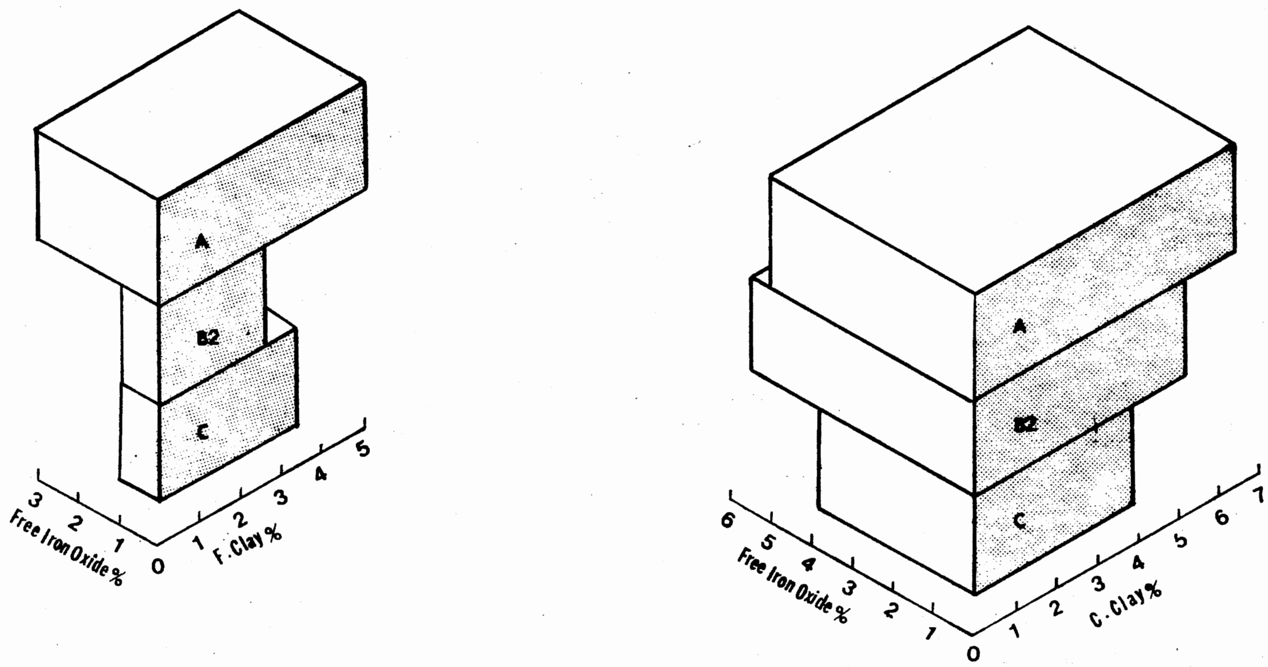

Figure 11. Free iron oxides percentage in the fine and the coarse clay for Quinlan soil.

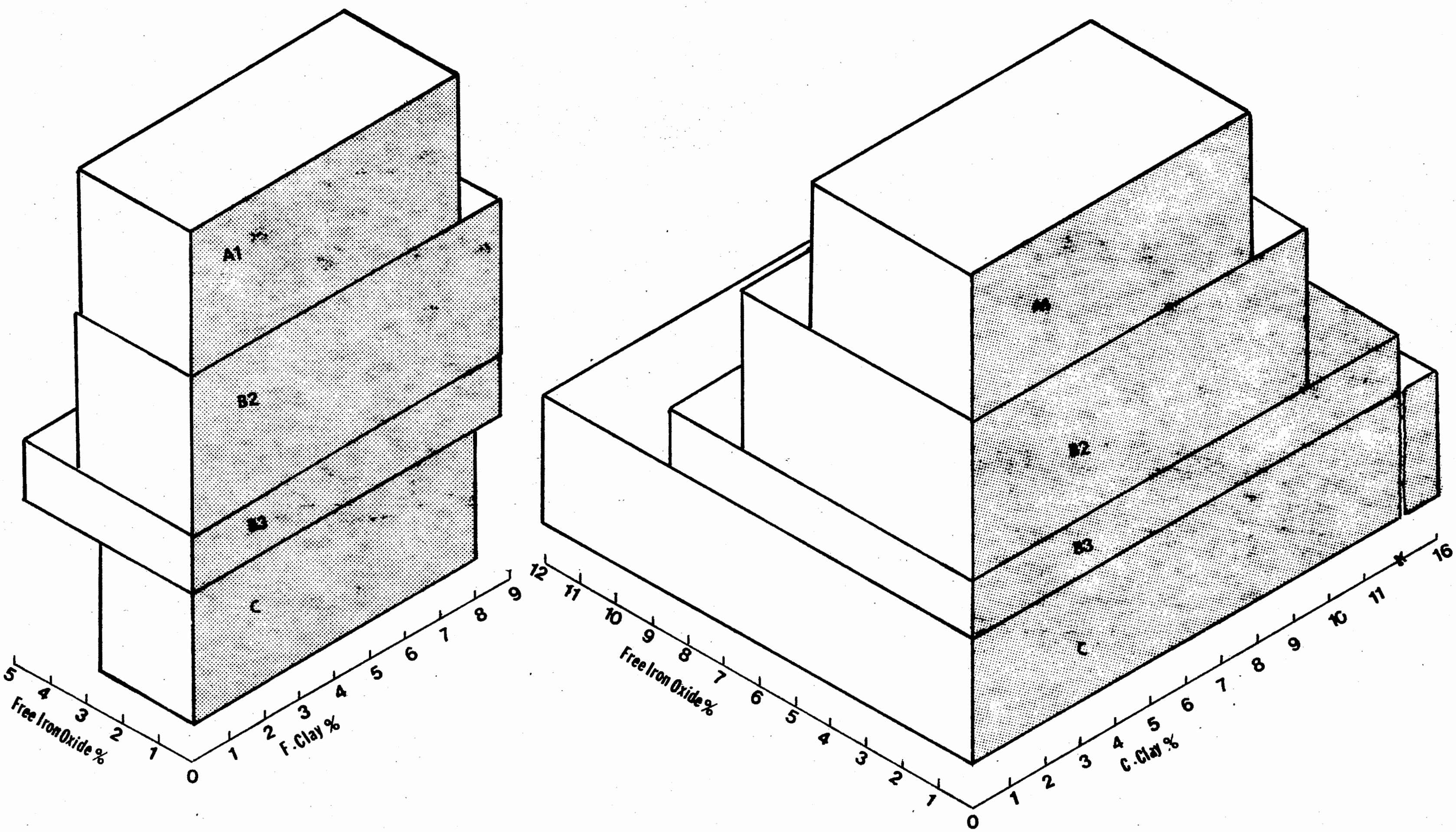

Figure 12. Free iron oxides percentage in the fine and the coarse clay for Woodward soil.

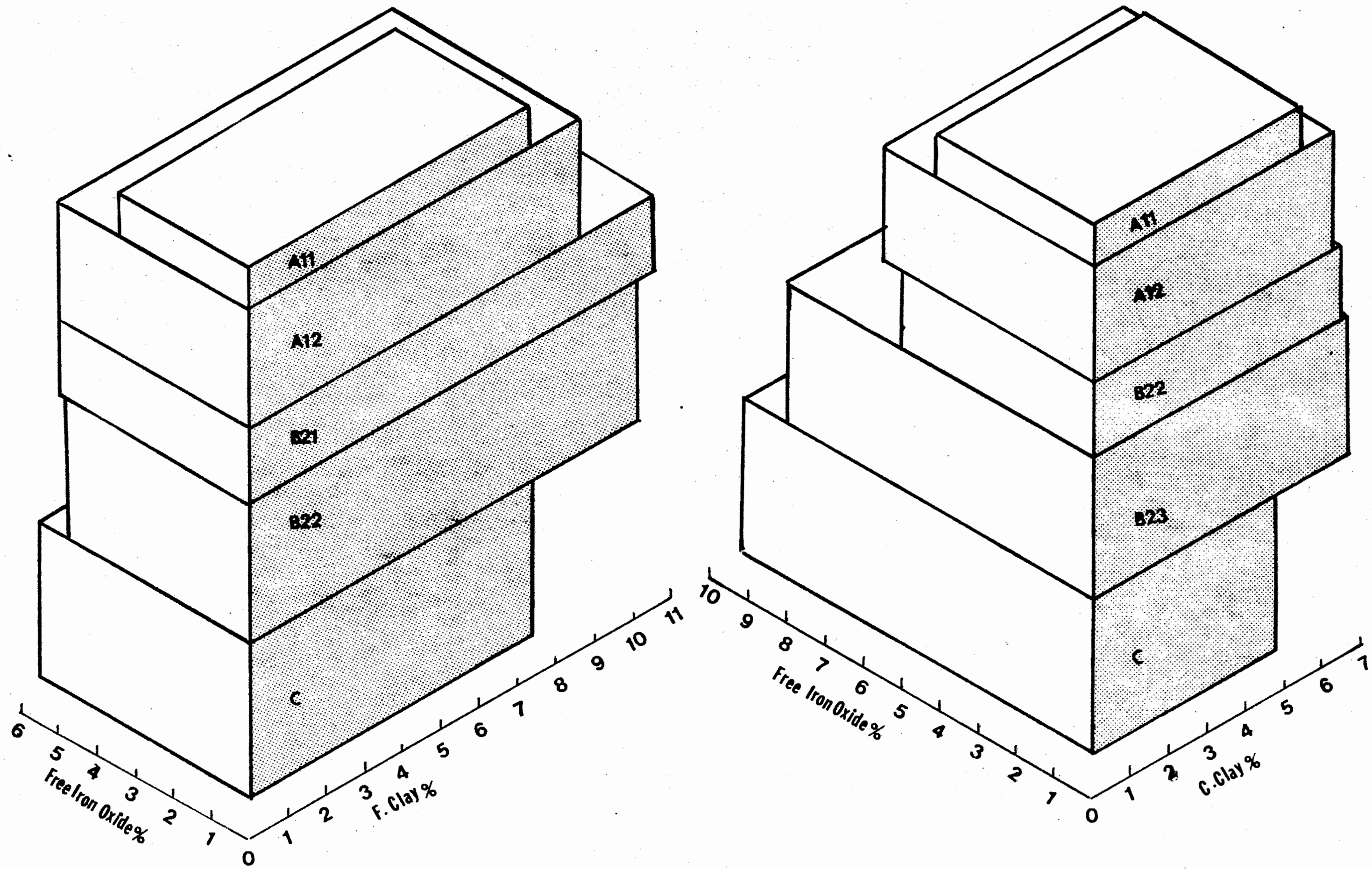

Figure 13. Free iron oxides percentage in the fine and coarse clay for Dill soil.

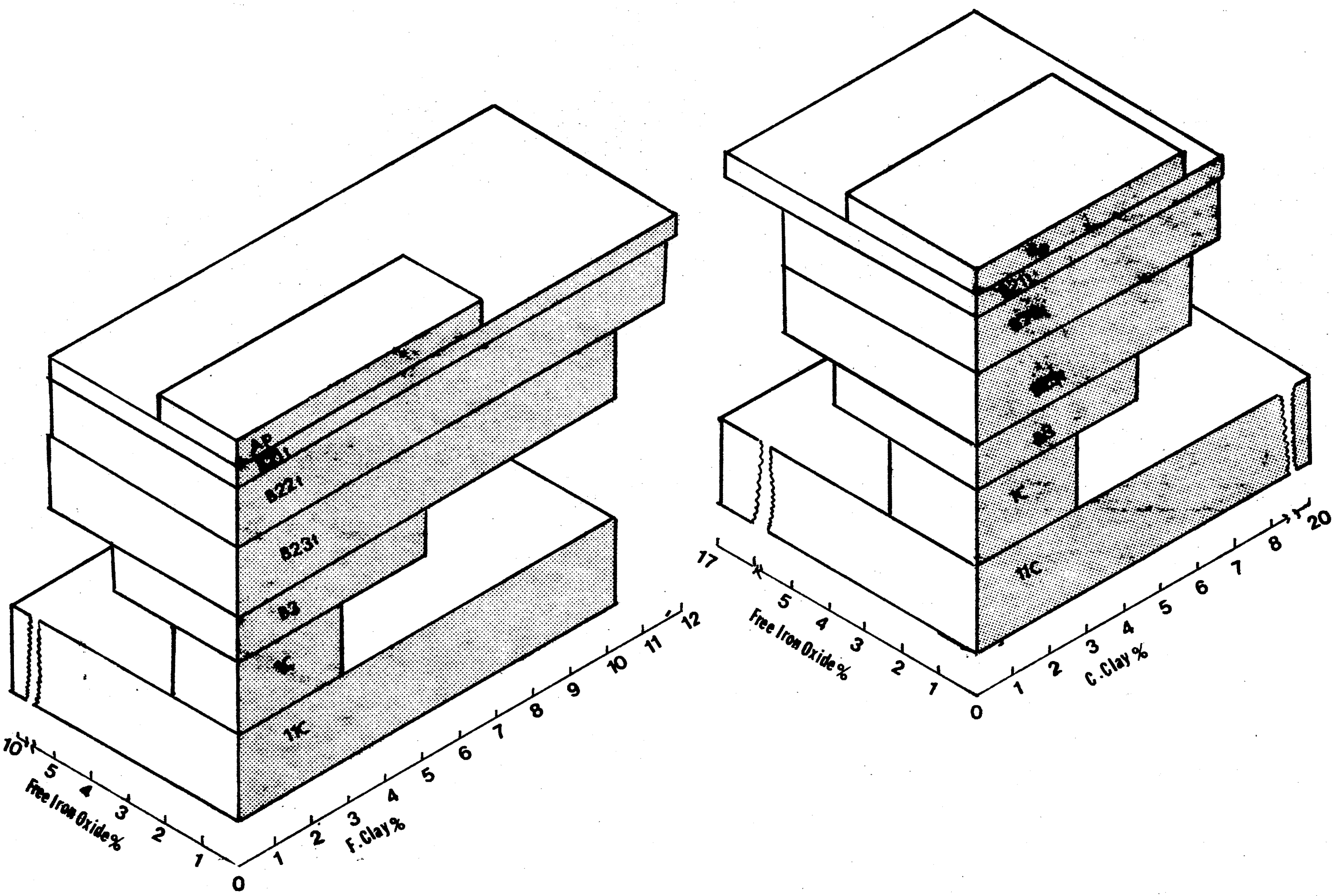

Figure 14. Free iron oxides percentage in the fine and the coarse clay, for Grandfield soil.

CHAPTER V

SOIL GENESIS

Cordell Soil

The general hypothesis of this soil genesis assumes that the soil formation factors were functioning on a geomorphologically stable topography, with no additions or losses of the initial parent material. The morphological, chemical and physical analyses indicate that the soil development factors have not contributed to a strong alteration of the parent material. This is expressed and reflected by weak morphological features. The stages of the soil development is hypothesized in the following sequence (Model 1, Figure 15).

Stage 1. The minimal stage of soil development begins with a hard siltstone material that is not high in calcium carbonate content. At this stage of development, no addition or deletions are assumed. The weak chemical and physical weathering reached a stage satisfactory to support prairie vegetation. The addition of organic matter, as enhanced by the grass vegetations, did not exceed the loss so that an ochric epipedon is developed and maintained. Though the parent material is low in calcium carbonate, leaching of bases were not extensive due to the grass vegetations effect which aided recycling the leached bases. This has kept the surface horizon rather alkaline and saturated with bases. However, the percolating water moving through the solum transferred some bases to the depth of water movement, resulting in the formation of a weak cambic horizon, and increased the thickness of the solum.

The negligible leaching of calcium carbonate and bases has contributed to the slight weathering of primary mineral and silicate clay.

Stage 2. At this stage of soil development, organic matter accumulation maintained an equilibrium with the environment. Therefore, the ochric epipedon is maintained throughout this stage of soil development.

Calcium carbonate leaching has proceeded further, but more intensively at the surface horizon. The downward movement, the deeper penetration of biological factors, and the accumulation of organic matter, the slight weathering of mineral to silicate clay at the surface, and the low content of calcium carbonate, aided in further expression and thickness of the cambic horizon.

At the present time, the soil morphology does not express a strong soil development. It reflects the development of a cambic horizon, high in pH, high in base saturation, and of low carbonate leaching intensity.

The particle size, iron oxides, and cation exchange capacity indicate that the weathering is still concentrated in the soil surface. No clay illuviation has been traced in this soil at this stage of soil development.

Quinlan Soil

The general hypotheses of the soil development assumes that the soil formation functions under a geomorphologically less stable upland site, with slight geological loss as the soil proceeds in aging. The approach to soil genesis for Quinlan soil (Inceptisol) is discussed below (Model

1, Figure 16).

Stage 1. The minimal stage of soil development begins with a calcareous or alkaline weakly consolidated sandstone or siltstone. The first stage is initiated by the slight change in the chemical and physical composition of the parent material to a satisfactory stage enough to support grass vegetation. This enhanced the accumulation of organic matter. The addition of organic matter did not exceed the loss and the development of ochric epipedon was quickly maintained. The high calcium carbonate content of the parent material acted as inhibitor of the bases leaching and the weathering of silicate clay. Furthermore, the grass vegetation aided in recycling the bases that has been leached by the moving water. This kept the surface saturated with bases and rather alkaline in reaction.

At this stage of development, no additon to the parent material had occurred; however, calcium carbonate are being continually transferred down from the surface by the downward movement of water. In addition to the vegetation effect, chemical and physical weathering contributed to the development of a weak cambic horizon.

Stage 2. As the soil leaves the first stage of development, continuous leaching of calcium carbonate proceeds to higher intensity especially in the surface horizon. The downward movement of percolating water aided in leaching and redepositing the calcium carbonate at a lower depth in the soil profile. This gave rise to more acidic conditions at the surface horizon, which in turn, accelerated the breakdown and reorganization of primary minerals to form silt and clay. At this stage, it seems that weathering is still concentrated at the surface. Nevertheless, it is assumed that part of the formed silt and clay has been lost by the running water. This contibuted to the development of the surface with less red color than the subsoil and the parent material. At this stage of development, the thickness of the cambic horizon is more expressed though some fragment of the parent material could be found in the subsoil.

At the present time, the calcium carbonate content of the solum is still high. Further depletion of this material is necessary to permit more base leaching and to accelerate more mineral weathering. No clay illuviation is traced by the particle size distribution, which beside the pH, cation exchange capacity, support the conclusion that the weathering in this soil is still concentrated at the surface horizon.

The morphological, chemical and physical studies suggest that this soil is still at the medial stage of development

Woodward Soil

The general approach for the genesis of the soil assumes that the soil formation was functioning under a less stable landscape. The genesis of Woodward soil is hypothesized in the following manner (Model 2, Figure 15).

Stage 1. This minimal stage of soil development begins with a parent material that is weakly consolidated, stratified, calcareous sandstone and siltstone. No addition or loss is assumed at this stage of development. The weak chemical and physical weathering helped the establishment of enough root zone to support the vegetation cover, which in turn, enhanced the addition to the organic matter. The accumulation of organic matter did not exceed the loss, therefore, the ochric epipedon quickly developed and maintained throughout this stage of

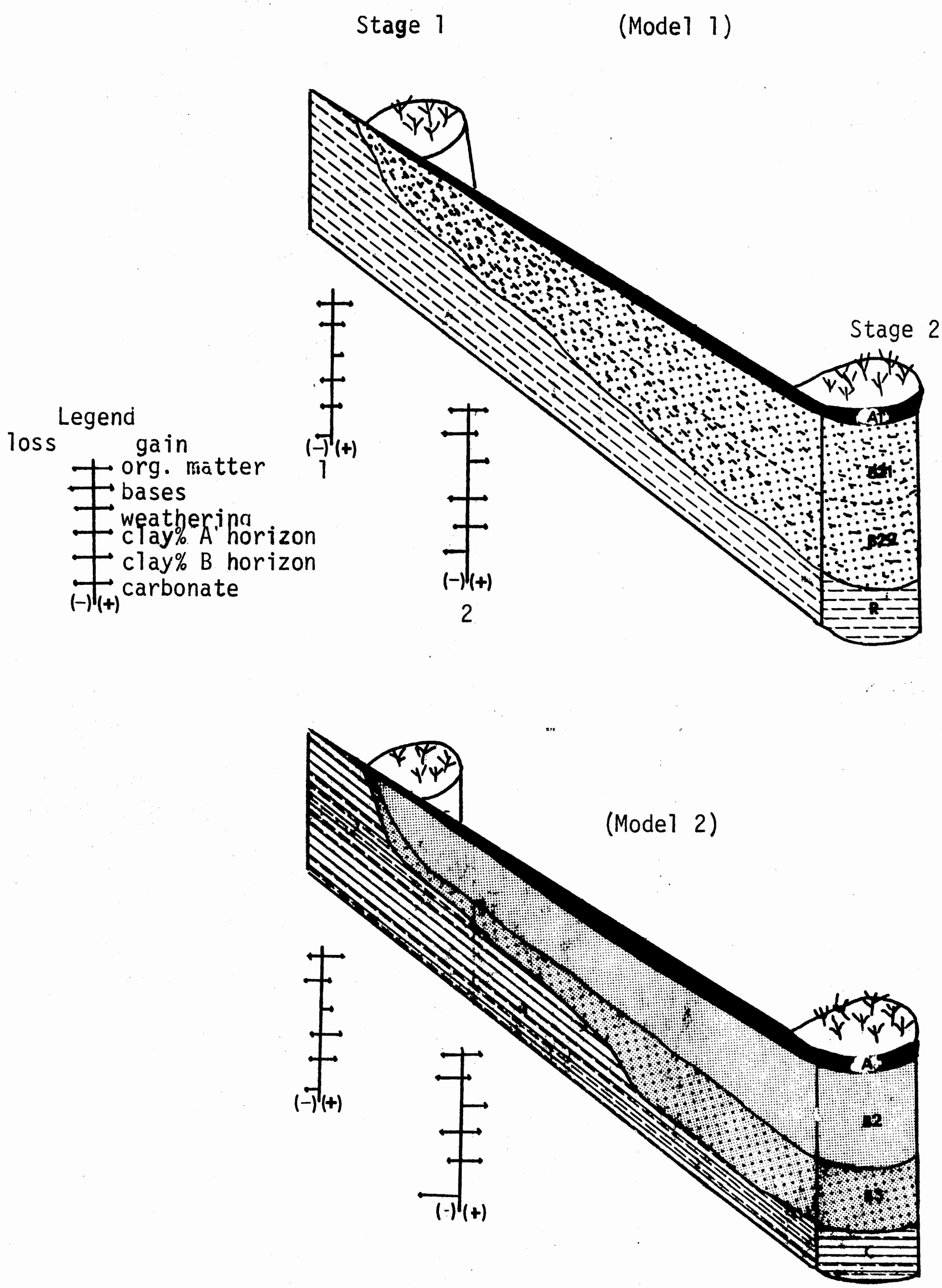

Figure 15. Proposed hypothesis model illustrating morphology changes and process rates for Cordell soil (model 1) and Woodward soil (model 2).

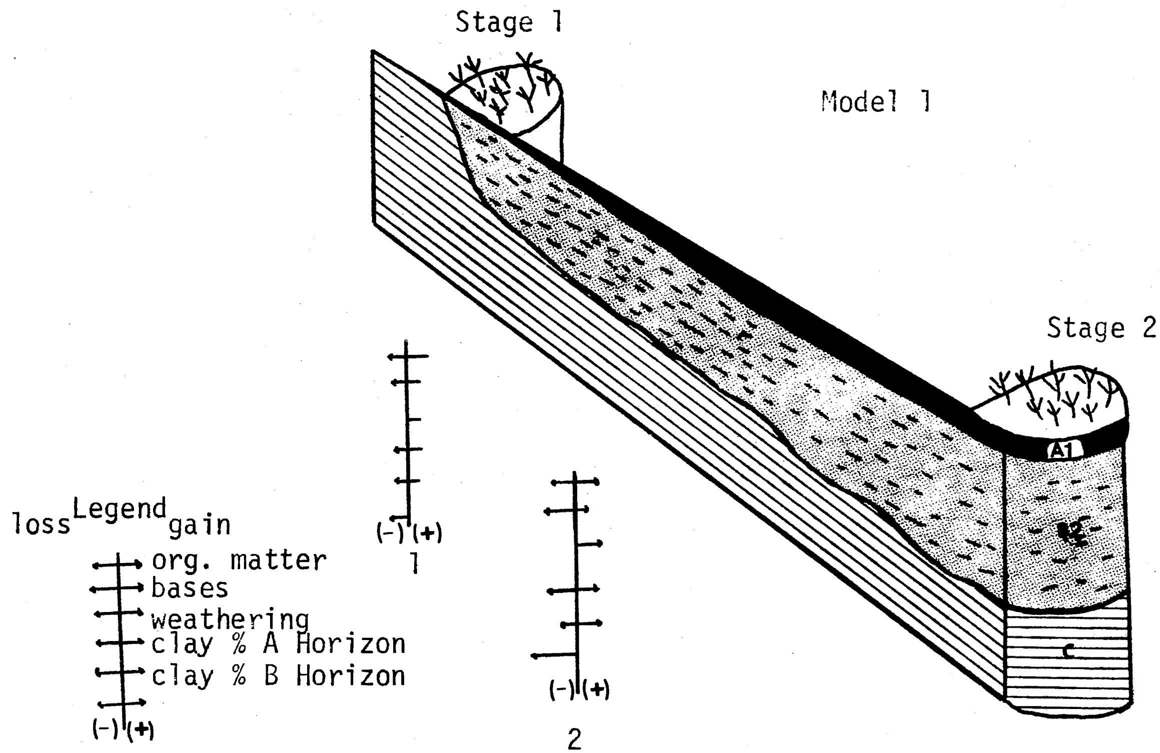

Figure 16. Proposed hypothesis of model (1) illustrating morphology changes and process rates for Quinlan soil.

development.

At this stage, the percolating water started moving some of the bases and the carbonate to the depth where the downward movement was reached. Nevertheless, the high carbonate content of the parent material acted as inhibitor to the weathering of the primary mineral to clay silicate. Thus, a weak cambic horizon developed as a result of the weak leaching of bases and carbonate. Furthermore, the surface horizon was kept rather alkaline due to the recycling of the bases by vegetation, which in turn, contributed to the weak weathering at this layer.

Stage 2. As the soil leaves the minimal stage of development, the cambic horizon is weakly expressed. The ochric epipedon has reached an equilibrium with the environment and maintained throughout this stage of soil development.

Downward movement of the water caused more bases and calcium carbonate leaching. This causes the surface to be less alkaline, enhanced the weathering in the surface horizon, and caused the ulteration of primary mineral to clay silicate. Running water contributed to the losses of some of the fine fraction of the soil especially the clay and the silt. This possibly is the reason of the development of the less red surface of the soil profile than the subsoil.

The deeper downward movement of the water caused further depletion of calcium carbonate and more bases which has been redeposited at the depth of the water movement. This gave rise to the development of soft secondary calcium carbonate film down in the subsoil. At this stage of soil development, the cambic horizon reached its maximum depth and it strongly expressed in features.

At the present time, the profile exhibits an increase in total clay with depth and so does the coarse clay, but the fine clay distribution and fine/coarse clay ratio indicates that clay has been accumulated in the profile as a result of weathering. In addition, free iron oxides data also confirm this finding. No clay illuviation was traced in this soil. At this stage it seems that further depletion of calcium carbonate is essential before the fine clay illuviation will commence.

Dill Soil

Dill soil has developed from sandstone material. Field study indicated that the processes of soil formation are functioning on nearly flat to undulating topography. The general approach to the genesis of Dill soil is based under the assumption that this soil has developed under a relatively less stable landscape. The slopes under this situation erode and retreat parallel to themselves as postulated by Pencks (28). According to Penck, the geologic down-wearing of the soil never reaches an equilibrium with soil development. The soil will continue to change older and older until the retreating slope destroys it.

The morphological, chemical and physical data are used in hypothesizing the sequence of Dill soil development (Model 1, Figure 17).

Stage 1. The minimal stage of soil development begins with calcareous stratified sandstone that average loam. This stage of soil genesis assumes no loss or gain. The physical and chemical weathering reached a depth enough to support the grass vegetation which enhanced the accumulation of organic matter at the surface layer. The high calcium carbonate content of the parent material inhibited the leaching of bases and the weathering of primary materials to form silicate clay minerals. A very weak cambic horizon has arisen as a result of the weak leaching of the bases by the percolating water moving through the profile. The grass vegetation helped recycling the leached bases and contributed to keep a predominantly alkaline surface.

Stage 2. As the soil leaves the minimal stage, a weak cambic horizon has already been formed. A continued intensive leaching of carbonate and bases leaching characterizes this stage of soil development. Accumulation and losses of organic matter apparently reached a state of equilibrium with the environment. The ocrhic epipedon is maintained throughout this stage of soil development. As the intensive leaching of calcium carbonate and bases leaching continues and advances deeper in the profile, lower pH throughout the profile accelerates the chemical and physical weathering intensively in the surface layer and to a lower degree in the subsoil. This also promotes the weathering of primary minerals to clay mineral silicate and increases the release of iron oxides. Running water apparently contributed to some losses of the silt and the clay from the surface giving rise to a less red color in the surface layer than it does in the subsurface. At this stage of soil development, it seems that the solum with strong cambic horizon has reached its maximum depth. Characterized by advance carbonate leaching and losses of bases giving rise to acid condition at the surface layer and acidic to neutral conditions in the subsurface.

Stage 3. This stage of soil development requires a maximal stable landscape which contributes to a more humid microclimate. As the soil reaches this stage of development, ochric epipedon is still maintained throughout this stage of development. The solum has been extensively depleted from its carbonate content. In addition to this, a further

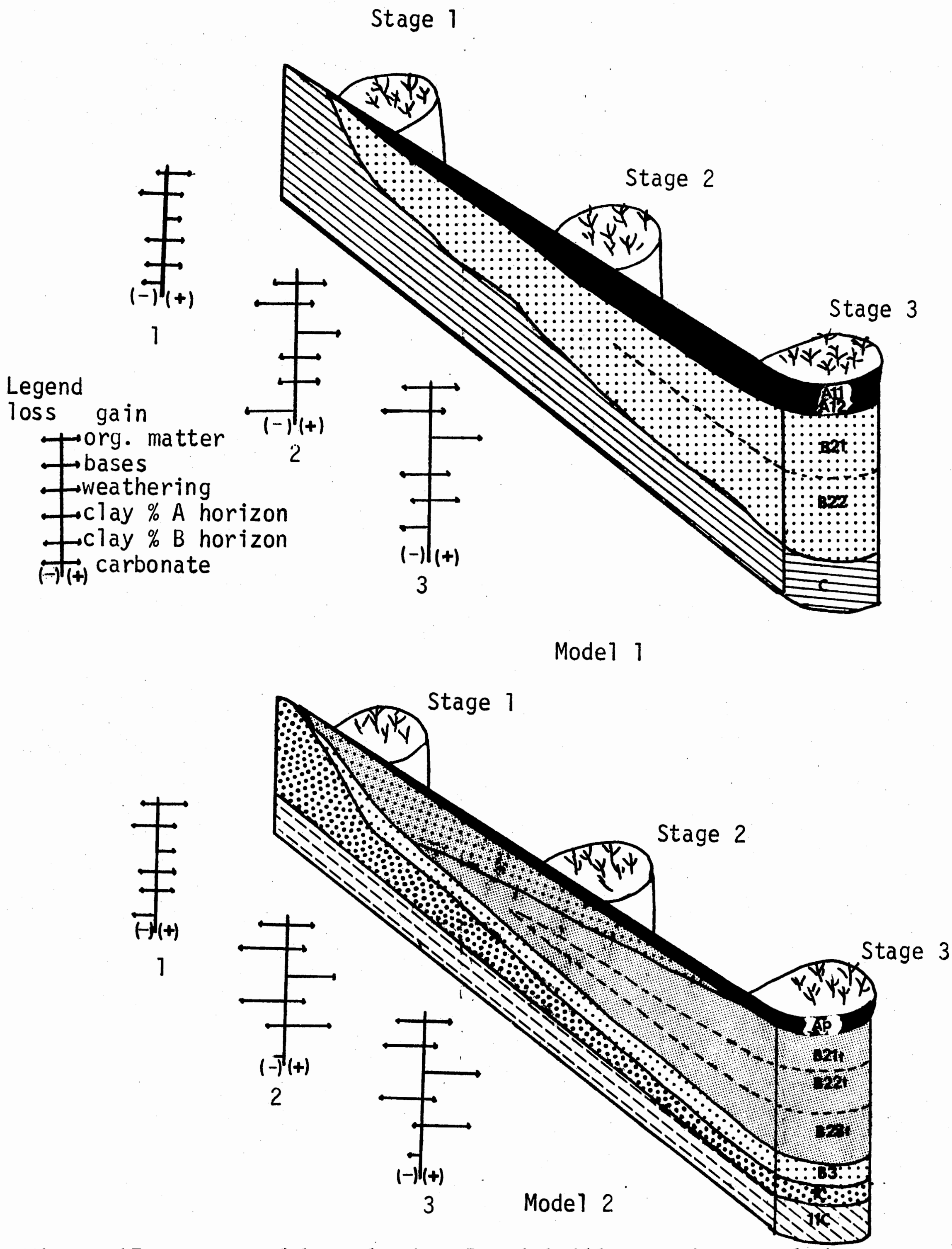

Figure 17. Proposed hypothesis of model illustrating morphology changes and process rates for Dill soil (model 1) and Grandfield soil (model 2).

loss of bases has contributed to lowering the pH at the surface and subsoil. This condition accelerated further soil weathering at the surface and promoted more silicate clay accumulation at the top of the profile. The carbonate content of the profile at this stage seems to be at the level which did not inhibit the clay illuviation. Therefore, the movement of the clay and especially the fine clay through the pores and the channel by the percolating water characterize this stage of soil development. At the present conditions, which represent the maximum development has been reached, the clay build up in the B horizon is not strongly expressed in the soil profile. This in turn does not allow the establishment of the argillic horizon in this soil. However, the particle size distribution, and pH cation exchange capacity data indicate that the path of soil formation is moving toward the evolution of argillic horizon and A2 horizon (though it has not yet expressed by the soil morphology). This situation reveals that the genetic pathway of this soil is converting from the Inceptisol to the Alfisol genetical pathway.

Grandfield Soil

A general hypothesis on soil genesis of Grandfield soil based on the study of the morphological, physical, and chemical analyses, suggest that this soil is not in equilibrium with its environment, but is continually aging slowly with time. The study of the genesis of this soil reveals a model of the following stages (model 2) that hypothesize the path of soil formation processes (Figure 17).

Stage 1 (minimal soil development). Soil formation factors started functioning shortly after the parent material was deposited by water.

The reworking by wind before the establishment of thick vegetative cover caused some losses in the finer fraction by deflation. The minimal stage of soil development begins with a loamy sand material that is low in calcium carbonate. No loss or gain is assumed at this stage of soil development. The physical and chemical weathering resulted in a sufficient depth of soil development to support vegetation which enhanced the addition of organic matter. Percolating water moving through the solum transfers some bases to the depth of the water movement. The low carbonate content accelerated the leaching of the bases. Due to good aeration, acidic conditon and losses of organic matter exceeded its accumulation so that an ochric epipedon was developed and maintained.

Stage 2 (medial soil development). The second stage of development of this soil constitues fast changing of soil properties. Bases leaching was not prohibited by the low content of calcium carbonate. Furthermore, the sandy nature of the parent material accelerated the rise of acidic condition. The organic matter accumulation apparently reached a dynamic equilibrium between gains and losses. Therefore, an ochric epipedon was maintained throughout this stage of soil development. Incipient weathering transformed primary mineral, oxidized iron, and caused the breakdown of silt to clay for more each translocation. At this stage, the calcium carbonate content was very low throughout the profile. This did not inhibit leaching of bases and weathering of silicate clay mineral. Percolating water moving throughout transfers clay especially fine clay to the depth of water movement. The translocated fine clays moved downward along root channels, cracks, and pores to a depth where they are deposited. At this stage a minimal argillic horizon rises in the profile.

Stage 3 (maximal soil development). This stage of soil development depends largely on a stable level relief. The addition and losses of organic matter remained in equilibrium with the environment. Therefore, ochric epipedon was maintained throughout this stage of soil development. The stable relief aided in a more humid micro climate, which in turn aid in the weathering processes. Further losses of the basis, lowering of pH, accelerates soil weathering in surface horizon. This promotes the continuing illuviaton of fine clay to the subsoil. As these processes continue, the fine clay blocks the small pores, channels, and gives further expression to the argillic horizon. Therefore, the downward movement of the water is restricted to a shallower depth. This causes the water to evaporate quickly and also to deposit the fine clay at a shallower depth, causing the argillic horizon to build up toward the surface. At this stage, clay bulge can be seen briding the sands particles.

Particle size distribution, pH, and cation exchange capacity suggest that the clay have been translocated from the A horizon to the argillic horizon.

Classification of the Soil

The soils were classified according to the soil taxonomy as follows:

Cordell soil - Loamy, Mixed, Thermic, Lithic Ustochrepts

Quinlan soil - Loamy, Mixed, Thermic, Shallow Typic Ustochrepts

Woodward soil - Coarse-silty, Mixed, Thermic Typic Ustochrepts

Dill soil - Coarse-loamy, Mixed Thermic Udic Ustochrepts

Grandfield soil - Fine-Loamy, Mixed, Thermic, Udic Haplustalfs

CHAPTER VI

SUMMARY AND CONCLUSIONS

SUMMARY

Cordell Soil

Calcium carbonate content suggests that the parent material of this soil is not highly calcareous. Nevertheless, the silty nature of the parent material in addition to the topographic location seems to restrict the deep penetration of the water. The calcium carbonate depth distribution suggests that the leaching of this soil is at the very early stage.

Particle size analyses of this soil indicates an initial accumulation of clay in the A1 and B21 horizons as a result of fine silt conversion to clay. The calculated ratio of coarse silt, very fine sand to fine silt confirms that soil weathering is mostly concentrated at the top layers (A1, B21). The weak development of the B horizon of this soil is reflected by the presence of few sandstone fragments in the B21 and the ample quantity of this fragment in the B3 horizon.

Particle size distribution, recalculated on the clay free basis, indicates a homogeneous parent material. The free iron oxides analysis provides a good insight of the weathering intensity. The data indicates that iron free oxides is more closely associated with the coarse fraction than it does with the fine fraction. This might suggest that very little conversion of coarse clay to fine clay has taken place.

Organic matter accumulation, as a function of vegetation, decrease gradually with depth reflecting the deep penetration of the plant root to initiate the biological weathering in the solum. Presently, it is reasonable to a-sume that organic matter accumulation, low degree of calcium carbonate leaching, the weak accumulation of the clay and A1 and B21 horizon, are the only soil formation processes active in this soil.

Quinlan Soil

The prairie vegetation enhances the addition of organic matter which results from deep penetration of plant roots. The restricted amount of water percolating through the profile seems to determine the depth and the extent of calcium carbonate leaching. Calcium carbonate leaching, which appears to be concentrated on the surface horizon, acts as an inhibitor of the basis leaching and the weathering of silicate clay.

Evidence from the carbonate leaching and from the particle size analyses suggest that soil weathering is still concentrated at the surface horizon. Free iron analyses from the fine clay of the surface horizon shows some increase of this material over the underlying horizon.

The slight difference in the organic matter content between A and B horizon might indicate that the biologically altered zone of this soil is deeper than does the chemically altered zone. Particle size analyses, especially f/c clay ratios, suggest no loss from the surface horizon to the subsoil. The silt and the sand fraction exhibit a contrast between the solum and the parent material. This contrast is confirmed from the examination of the particle size composition recalculated on the clay free basis.

At the present time, accumulation of organic matter, leaching of calcium carbonate, and the slight accumulation of clay of the surface horizon are the dominant soil forming processes.

Woodward Soil

Total clay in this soil increases with depth. C horizon contain the highest amount of clay. The sand and silt fraction also follow the same pattern. The fine clay content fraction in the solum seens to be increasing as the result of the weathering. This is obvious from the vertical distribution of the fine/coarse clay ratio which decreases with depth. Another evidence of the fine clay accumulation in the profile is drawn from the free iron analyses. The free iron of the coarse fraction increase with depth and follows the coarse clay distribution, but the free iron of fine clay fraction of the solum seems to gain over the parent material following the same pattern as the fine clay does.

The gradual decrease in organic matter in the profile reflects the effect of the grasses and the deep penetration of the roots.

Leaching of calcium carbonate has advanced in the profile deeper than Quinlan and Cordell. Soft secondary calcium carbonate films have developed at the lower part of the profile. This reflects the depth of water percolation and the extent of the calcium carbonate leaching. Nevertheless, no sign of clay illuviation could be traced from the surface horizon downward, but rather in situ accumulation. It seems that further depletion of calcium carbonate is necessary before clay illuviation could commence.

Dill Soil

Calcium carbonate data demonstrates that leaching has been deepened intensively in this soil. This finding is substantiated by the vertical distribution of the base saturation and the acidic nature of the solum. The extensive leaching of the profile has been reflected on the morphology by the development of the soft autogenic calcium carbonate in the lower part of the solum.

Particle size analyses carried on the major and subsampled horizon indicates a moderate increase in the clay content of the solum. Examination of the fine clay and fine/coarse clay distribution proved that clay illuviation has reached a satisfactory stage enough establish an argillic horizon. Testing the change in the amount of total clay that started building up on the subsoil does not permit this soil to have an argillic horizon as required by soil taxonomy. It seems obvious that calcium carbonate leaching in this soil has reached the stage to allow fine clay illuviation. Free iron oxides for both coarse and fine clay follow closely the depth distribution of both fine and coarse clay indicating the status of soil weathering.

Particle size distribution calculated clay free-basis suggest a stratification in the transition area between the solum and the parent material. Clay illuviation and elluviation processes and the CEC and pH values for the A12 and B21 horizonx, suggest that the weathering in this soil has reached a stage enough to start building up an A2 (elluviation) horizon and Bt (illuviation horizons). Though the biological activity reflected by the accumulation of the organic matter is deep. It appears that the chemical weathering processes also is deep enough to coincide with biological weathering.

Grandfield Soil

Grandfield soil has developed in loose sand and sandy clay of the Quaternary or the Tertiary age which was deposited either by wind or water. The absence of coarse particles larger than 2 mm in addition to the presence of few rounded pebbles suggest that this soil has been reworked by wind after being deposited by water. This conclusion could be verified by examining the particle size distribution recalculated on a clay free basis and by the ratio of coarse silt and very fine silt to fine silt which indicate high loss of silt from the surface horizon, possibly by wind deflation.

The sandy nature of this soil provides a good path for the percolation of the water. The soil is acidic in reaction. The calcium carbonate is very low. It seems that the limited amount of calcium in the profile did not prohibit the illuviation of fine clay.

Particle size distribution for this soil indicates that the change in the total clay and f/c clay ratio has been enough to build up a weak argillic horizon in the subsurface zone. Furthermore, the base saturation status of the soil, and the close relationship between the free iron oxides and the fine clay distribution suggests that the podzolization processes has exceeded its preliminary stage. Organic matter distribution indicates only accumulation at the surface shows no sign of organic matter illuviation.

CEC depth distribution shows a close relationship with the distribution of the fine clay. This suggests that fine clay illuviation is responsible for the rise of the CEC in the argillic horizon.

At this stage of development, it seems reasonable to assume that elluviation and illuviation of both fine clay and iron oxides is the most important soil formation processes acting in this soil.

CONCLUSION

As a result of the morphological, chemical, physical studies. It seems that many properties appear to increase in intensity or magnitude, or degree of expression, from one soil to another. The soils could be arranged in the following manner from the soil that exhibits the lowest values of their properties to the highest as follows:

Cordell - Quinlan - Woodward - Dill - Grandfield. These properties are:

1. The accumulation of the clay at the surface (except Grandfield soil) which exhibits clay illuviation in the profile.

2. The leaching intensity and the development of the secondary calcium carbonate in the profile (Grandfield is not included here since the carbonate content is almost negligible).

3. Clay illuviation.

4. The inclination of the free iron to be more associated with the fine clay.

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CHAPTER VII

LITERATURE REVIEW

Soil is the result of the integrated effect of several external and internal factors acting upon the geologic material (Jenny, 21). These factors act under widely different conditons. Under the effect of these factors, the parent material undergoes changes which result in producing material that differs from the original material. The new material that has been chemically and physically changed in the presence of the biological factor, is called "soil" (Marbut, 27). Several features distinguish the soil from the original material. These features can be summarized as follows (7): (1) the chemical composition, (2) the physical makeup, (3) soil always has a definite thickness, (4) soil is always more or less colored and (5) soil reacts to heat, moisture and growth of vegetation.

Two types of weathering dominate the processes of parent material ulteration (John Cady, 23). In the first type, the weathering advances along a sharp front leaving secondary resistant mineral on which the soil develops. The solum which develops under such conditions is rather featureless and without structural differences, but chemically and mineralogically is uniform. The boundary between the solum and the parent material is so sharp that the mineral composition changes over very short distances measured by millimeters.

In the second type, the weathering of the parent material advances in away that the ultered material contains weatherable mineral. Different reactions take place in this material and at different depth. Under such conditons, the boundary between soil and parent material cannot be located as sharply as the first type. The change in the mineral and chemical composition from the solum to the parent material tends to be rather gradual.

Immediately after the formation of the parent material from the geologic column, the soil formation processes start operating on the newly formed material. These processes act as a complex of or as a sequence of events including both complicated reactions and comparatively simple rearrangements of the fabric material. The result of these processes is the development of horizons from which the soil genesis could be reconstructed.

Simonson (32) considered that horizon development can be due to four processes; addition, removal, translocation, and transformation. These processes operate in all kinds of soil, but at a different intensity. The relative importance of each process is not uniform in all soil. Consequently, it may result in enhancing or offsetting the horizon differentiation. The development of the soil profile results from the differential movement of the mobile constituents by downward or upward movement, either in solution of in suspension (18) or by mechanical transport. The downward movement is almost entirely related to the movement of water. The profile differentiation has been the result of the balance of leaching, even the effects of organic matter are considered a reflection of this. Leaching system effects the rate of decomposition or organic matter. If production of organic equals the decomposition, accumulation of certain constituents like sesquoxides rather than loss would occur (16).

Calcium carbonate is one of the most important constituents of the soil. It is affected by leaching and plays an important role in the soil development. Its importance arises from the accessory pedogenic properties that develop in the soil profile and can be recognized in the field description of the soil. Calcium carbonate is a unique constituent of soil that occupies extensive areas of the earth's surface (2, 20, 15). It may exist in the parent material or produced by reaction between carbonic acid and calcium hydrolized from a mineral material. Calcium carbonate is moved by percolating water as calcium bicarbonate and precipitated again where the percolating water stops as calcium carbonate.

Calcium ions is an effective collodial flocculating agent. Thereby, high calcium status in the soil seem to keep the clay a flucculated state, retard the clay illuviation processes, and the development of the Bt horizon of silicate clay accumulation (20, 8). While carbonates are present, enough calcium ions get into the soil solution and result in decreasing the solubility of primary silicate minerals.

Raad et. al. (30) found that leaching of calcite is a function of the amount of water moving through the profile. Others (20) found that during the early stages of soil development leaching of carbonate is a function of solubility equilibrium of the mineral.

Harper (22) has noticed the effect of calcium carbonate in retarding weathering processes including the formation of silicate minerals. He also noticed that in any given profile developed in uniform parent material texture may be comparatively finer in horizon of calcium carbonate accumulation, but the distribution of clay silicate particles is almost constant throughout. Gile (13) reported difficulties of recognizing argillic horizon due to calcium carbonate accumulation. In addition, accumulation of calcium carbonate affected the estimation of silicate clay which is necessary to assess the requirement for clay increases due to fineness of calcium carbonate grains.

Soil genesis has been reported to be markedly the weathering of carbonate (1, 8). Limited pedogenic properties have developed until Ca and mg are largely removed from the solum.

Generally, it has been reported as a rule (26) that the clay content decreases and the calcium carbonate equivalent content increases with depth. However, it remains constant after reaching certain depth.

Gile (12) found that the illuviation of clay has not been demonstrated in desert soil formed in sediment containing an abundance of calcium carbonate. He also found (13) that the carbonate accumulation is involved in the obliteration of argillic horizon. He noticed that the illuviated clay horizon (14) is not always as prominant. In some soil, argillic horizon have not developed because of high carbonate content of the parent material or because the soil is young. In his study of Rio Grande Valley soil, Gile (12) found that horizons of calcium carbonate is more related to soil age rather than silicate clay accumulation.

It seems that age (13) and carbonate content of parent material are important factors in the development of illuviated clay horizon. It was found that an argillic horizon may first appear in Holocene soils that have formed in low-carbonate parent material, or in soils of the Pliestocent, if the parent material contains only moderate amounts of carbonate.

In other studies, it was found that in soil rich in calcium carbonate (12) increases in soil development is shown not only by the degree of development of genetic horizons, but also by solum thickness which increases with increase in age (12). Generally, thickness of B horizon is not well related to soil age. This is due to the engulfment of lower parts of the argillic horizon by the carbonate (8, 12, 11) and that the illuviate clay has not been demonstrated in desert soil formed in sediments containing abundant fragments of calcium carbonate, even in soil of lage-pliestocene age. In addition to this, Gile (13, 10) noticed that the illuviated clay horizon becomes less red and lighter in color with more calcium carbonate accumulation. He also found as calcium carbonate continues to accumulate, the soil becomes yellower than 5YR. In addition, the oriented clay was correlated with the change in color. The point at which the horizon in the B position contains two little oriented clay is marked by slight change in color. If part of the horizon of silicate clay accumulation is reddish brown or red, then enough oriented clay usually remains for the horizon to qualify for argillic horizon.

It seems obvious that soil profile development is the outcome of two overlapping trends of soil formation (17). The first trend induces the soil horizonation. The second trend which is termed haplodization, obliterates the work of first group of processes. This counteraction makes it difficult to recognize the depth to which the soil forming processes has reached. Thus, the soil lower limit to parent material beneath is perhaps the most difficult to define and recognize.

When Dokuchayev described the chernozem soil, he defined the lower boundary of the soil as where the visible coloration disappears in the profile (6) Blinka (9) considered it wrong to draw the lower boundary of the soil at the depth of humus penetration. Later on Kostychev (24) suggested that the boundary of the soil reaches its maximum depth where the main mass of plant roots penetrate, and that the parent material differs from soil in that the later serves as medium for all biological activity.

The changes that take place in the geochemically weathered upper portion of the geologic column, and in the presence or influence of the biological forces, is called soil formation. Holding this view, Marbut (27) stated that "the soil is that layer of the earth's crust laying within reach of those forces which influence, control and develop organic life." Kellogg (25), in his discussion of "building material for soil", favored Marbut's view that the soil formation from the parent material is neither physical nor strictly biological but a combination of both.

Jackson (22) argued the point that when the definition of soil is restricted to that portion of geological column upon which biological forces are acting. Many soils have developed with little pedochemical weathering of minerals. Under this restriction, the mineral content of solum will be similar to that of the C horizon. In highly weathered geologic columns with high mineral pedochemical weathering, if the soil is restricted to the portion of geologic column upon which biological forces have acted, the main chemical weathering occurred in the parent material formation (28). In this case, the mineral content of the solum differs from that in the immediately underlying parent material.

In some cases, chemical weathering may coincide with the depth of biological activity and soil development. In this situation, the coincidence of the depth of rock weathering with the soil formation arouse the interest of the soil scientists in chemical weathering because soil can form only due to the changes in the rocks brought by chemical weathering. Some soil scientists preferred to extend their definition of soil to include the weathered zone (5, 21). Thus Glinka (9) suggested that the term soil should be considered as the entire profile of the weathering crust and the soil boundary should run where the weathering crust terminates. He modified this concept where he considered the depth of the soil should be determined by the depth to which parent material has been modified by the soil formation processes.

It is quite obvious that the concept of soil lower boundary with the existing different kinds of soils that develop by a large number of forces is very difficult to define in general form. This makes the recognition of the boundary between soil and parent material in the field very difficult. Nevertheless, it seems that there is a general agreement to consider the lower limit of soil as the lower limit of the biologic activity which generally coincides with the common rooting depth of native perennial plants (32).

CHAPTER VIII

METHOD AND MATERIAL

Soil Sampling

Major horizons were described and sampled as outlined in Soil Survey Manual (35). Subsamples were taken for detailed study of the zone between B and C horizons. Roots distribution were studied by counting number of roots per 100 cm^2 of each layer. Calcium carbonate concretions (films) were observed and recorded at the time of the sampling. Abundance, size and contrast of the concretion were recorded according to Soil Survey Manual (35).

Physical Analyses

Bulk Density

Bulk density was determined by coating natural clods with saran resin dissolved in methyl-ethyl-keton 1:4 by weight (4). The volume of the clod was measured by subtracting weight of the clod in water from its weight in air. Oven dry weight was determined by drying the clods at 105°C for seven days to reach a constant weight. The bulk density was calculated utilizing the following equation:

$$\text{Bulk density} = \frac{\text{volume of the soil}}{\text{oven dry weight}}$$

Note: Since mechanical analyses indicate the absence of fraction coarser than 2mm, value of bulk density reported here represents bulk density for earth material less than 2mm.

Chemical Analyses

Organic Matter

Organic matter was determined by the addition of 10 ml of 0.4 N potassium dichromate, 15 ml of concentrated sulfuric acid, and heating of the sample to 161°C A. The samples were titrated against 0.2 N ferrous ammonium solution (31).

Carbonate Equivalent

Carbonate equivalent was determined by the acid neutralization method (29). 50 ml of standardized HCL was added to 5 gms of soil to react with the carbonate. The samples were boiled gently for five minutes. The samples were leached and the excess HCL was titrated against standard NaOH to the end point using phenophthalein as an indicator. Calcium carbonate equivalent percentage was calculated by subtracting equivalent of used NaOH from HCL equivalent added.

Soil pH

The soil pH was determined by using the Backman pH meter on a 1:1 soil water mixture (34).

CHAPTER IX

Discussion

CHEMICAL MEASUREMENT

Calcium Carbonate Equivalent and Leaching Intensity

Cordell Soil

(Table X) shows the calcium carbonate equivalent for Cordell soil. The data indicates that Cordell is not highly calcareous soil. A horizon contains 33.3 meq $CaCO_3$/100 gms of soil. This value increases gradually with depth. The R layer contains the highest calcium carbonate content. Data for subsamples indicate the uniform calcium carbonate distribution in the parent material. (Figure 18) shows no significant difference between the different horizons, but does indicate the gradual increase in the carbonate content from A to C horizon.

Based on these data, it might be reasonable to suggest that the calcium carbonate leaching in this soil is still at its initial stage.

Quinlan Soil

Calcium carboante equivalent content distribution exhibits a maximum leaching of this component at the surface horizon. (Table X)shows the verticle distribution of calcium carbonate equivalent. The calcium carbonate increase rapidly from 86.6 meq at the surface horizon to 316.4 meq at the lower part of B horizon, then it decreases gradually in

TABLE X

CHEMICAL AND PHYSICAL ANALYSES OF SUBSAMPLES OF GRANDFIELD AND QUINLAN

Depth cm	Organic Matter %	Roots Number/ 100 cm^2 of Vertical Exposure	Leaching Intensity	Total CO_3 meg 100gms of soil	pH 1:1 H_2O	Bulk Density gm/cm^2
			-----Grandfield-----			
0- 18	1.00	50	1.00	6.66	5.55	1.72
18- 33	0.97	44	0.50	13.30	6.35	1.74
33- 76	0.52	21	1.00	13.30	6.00	1.76
76-122	0.36	20	1.00	6.66	5.80	1.83
122-155	0.27	16	1.00	6.66	6.00	1.67
155-178	0.12	10	1.00	6.66	6.15	1.67
178-196	0.09	8	1.00	6.66	6.25	1.76
196-201	0.06	5	1.00	6.66	6.35	1.82
201-206	0.06	5	1.00	6.66	6.40	1.80
206-221	0.16	4	--	13.30	6.50	1.86
221-279	0.02	1	--	40.00	7.60	1.90
			-----Quinlan-----			
0- 23	1.41	90	2.77	86.60	7.75	1.54
23- 36	1.34	91	0.94	253.70	7.95	1.40
36- 41	1.26	75	0.80	296.50	7.95	1.40
41- 46	1.28	83	0.75	316.40	7.90	1.54
46- 51	1.04	45	0.88	273.20	8.00	1.70
51- 64	0.52	11	1.00	239.90	8.10	1.73

TABLE XI

CHEMICAL AND PHYSICAL ANALYSES OF SUBSAMPLES OF WOODWARD, CORDELL AND DILL SOIL

Depth cm	Organic Matter %	Roots Number/ 100 cm^2 of Vertical Exposure	Leaching Intensity	Total CO_3 meq/ 100gms of soil	pH 1:1 H_2O	Bulk Density gm/cm^3
			-----Woodward-----			
0- 36	1.93	47	7.298	56.6	7.55	1.54
36- 74	1.00	35	1.32	313.1	7.90	1.51
74- 81	0.80	13	1.10	386.4	8.00	1.59
81- 86	0.78	23	1.10	386.4	7.92	1.59
86- 91	0.66	21	1.10	386.4	8.00	1.66
91- 97	0.62	26	1.03	399.8	8.20	1.74
97-114	0.59	4	1.00	413.1	8.20	1.76
			-----Cordell-----			
0- 18	2.07	200	1.40	33.3	7.60	1.50
18- 28	1.84	170	1.40	33.3	7.86	1.50
28- 33	1.84	153	1.40	40.0	7.85	1.52
33- 38	0.88	75	1.16	40.0	7.92	1.85
38- 43	0.54	66	1.00	46.6	8.10	2.00
43- 64	0.15	2	1.00	46.6	8.20	2.00
			-----Dill-----			
0- 10	1.76	80	14.99	20.0	6.50	1.52
10- 36	1.19	75	14.99	20.0	6.40	1.49
36- 53	0.85	75	12.86	23.3	6.50	1.55
53- 69	0.83	64	14.99	20.0	6.60	1.57
69- 76	0.85	63	14.99	20.0	7.30	1.69
76- 84	0.66	55	1.08	276.5	8.00	1.81
84- 94	0.30	28	1.05	283.2	8.10	1.86
94-119	0.04	8	1.00	299.8	8.30	1.88

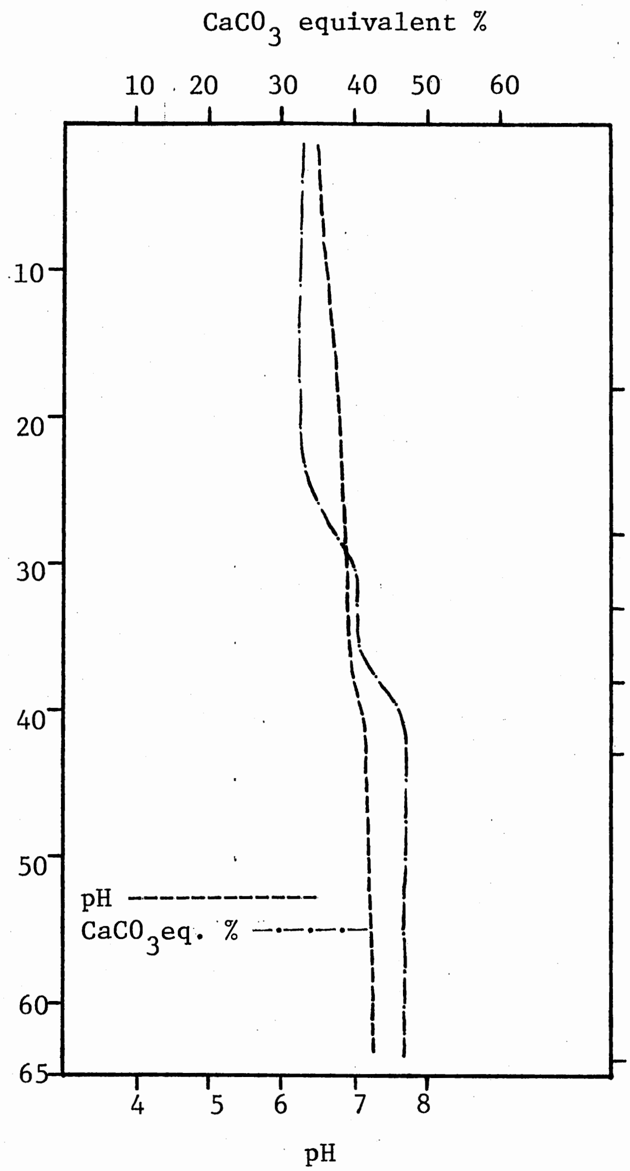

Figure 18. pH, calcium carbonate equivalent-depth distribution for Cordell soil.

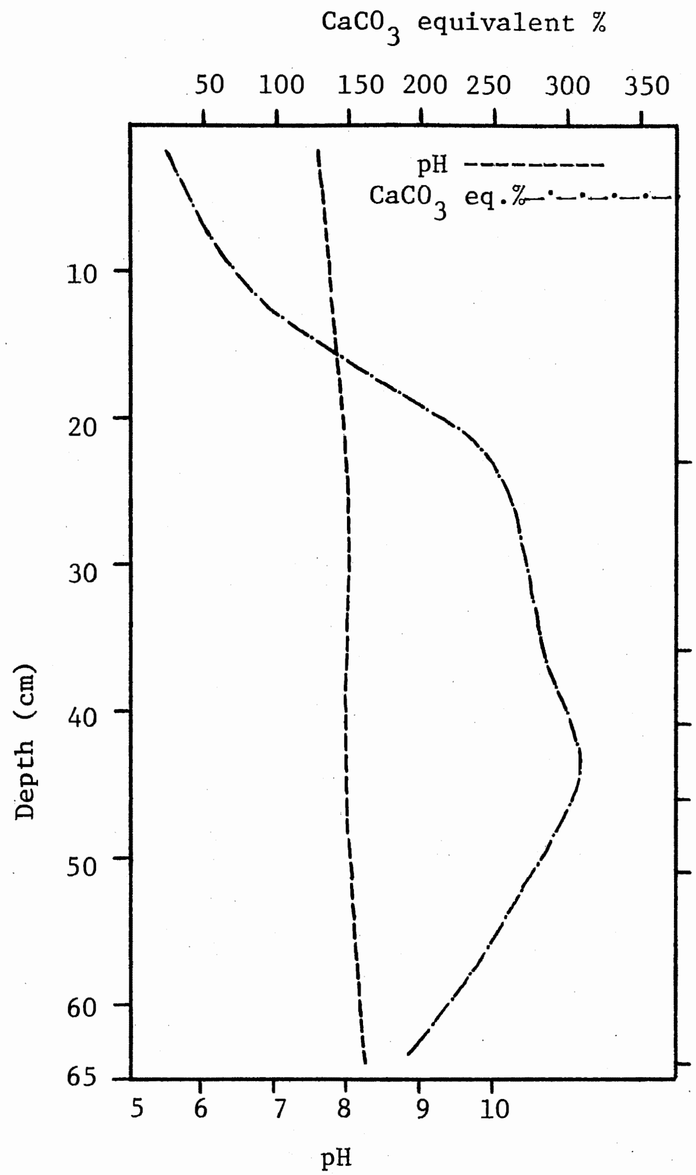

Figure 19. pH, calcium carbonate equivalent-depth distribution for Quinlan soil.

the C horizon. These values suggest that the calcium carbonate has been leached from the A horizon and reaccumulated in the B horizon (Figure 19). If compared with Cordell soil, it seems that the calcium carbonate distribution in this soil exhibits more advanced stage of leaching than it does in Cordell soil.

Woodward Soil

(Table XI) shows the calcium carbonate content for various horizons. The carbonate equivalent content for A horizon is 56.6 meq/100 gms of soil. Data from subsamples indicates that the carbonate content increases rapidly in B2 and to the top part of B3 where it levels off at the zone between B and C horizon. In this pedon C horizon maintains the highest carbonate content (Figure 20). Very few films of soft secondary calcium carbonate were observed at the lower part of the B3 horizon. This gives a good indication about the depth of water percolation and the extent and intensity of calcium carbonate leaching. This substantiates the conclusion that the leaching has been active to a moderately deep zone. Accordingly, leaching in Woodward soil could be placed at a little more advanced stage than it does in Quinlan soil.

Dill Soil

Calcium carbonate equivalent indicates that the solum of this soil has been highly leached. Calcium carbonate equivalent/100 gm of soil for A horizon is 20 meq and averages from 20 to 23.3 meq in the subsoil. The vertical distribution of this component (Table XI) is almost uniform in the solum. The carbonate content increases sharply at the transitional zone between the lower part of the B22 and the C horizon. C horizon maintains the highest carbonate content (Figure 21). Dill soil has developed under the same climatic conditions as Cordell, Quinlan and Woodward did, but due to the more gently undulating topography occupation, in addition to the sandy nature of the parent material, it seems that this condition creates a more humid microclimatic environment. This will allow more and deeper water percolation in the profile. The development of the soft secondary calcium carbonate films is a good indication of depth of water percolation and the carbonate leaching. Some of the calcium carbonate films occur in the zone of low calcium carboante equivalent. It seems that these films are reminant of a zone that was high in carbonate at one time. As leaching processes proceeded this zone has been stripped of its carbonate content. Holding this view, it seems likely that carbonate leaching in Dill soil represents the most advanced stage among the studied soils.

Grandfield Soil

Grandfield soil has developed in alluvial sandy material. The sandy nature of this soil provides a good path for the percolation of water.

The calcium carbonate equivalent for various horizon (Table X) indicates that this soil is very low in calcium carbonate. The carbonate equivalent averages from 6.66 meq/100 gms of soil throughout the entire profile and 13.33 meq in some parts of the argillic horizon. No significant leaching could be traced in this soil except the very little increase in the carbonate content of B21t and B22t. The low content of calcium carbonate content is reflected by the pH value which indicates that this soil is of acidic reaction throughout the profile (Figure 22).

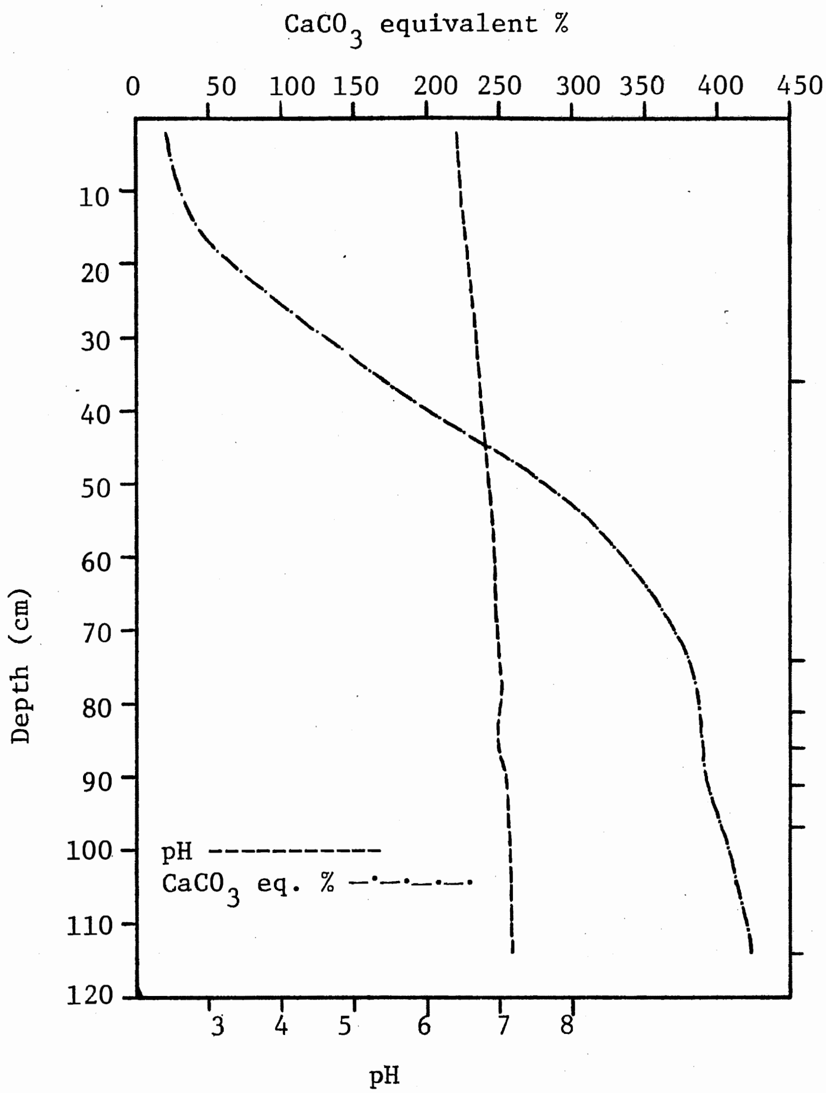

Figure 20. pH, calcium carbonate equivalent %-depth distribution for Woodward soil.

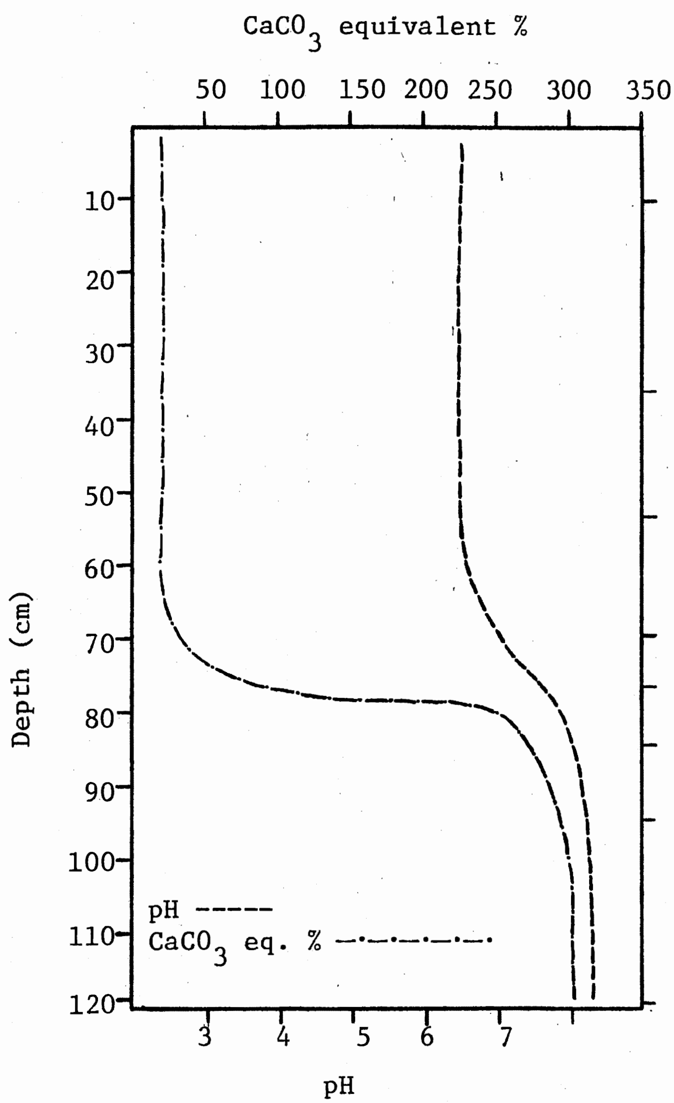

Figure 21. pH, calcium carbonate equivalent %-depth distribution for Dill soil.

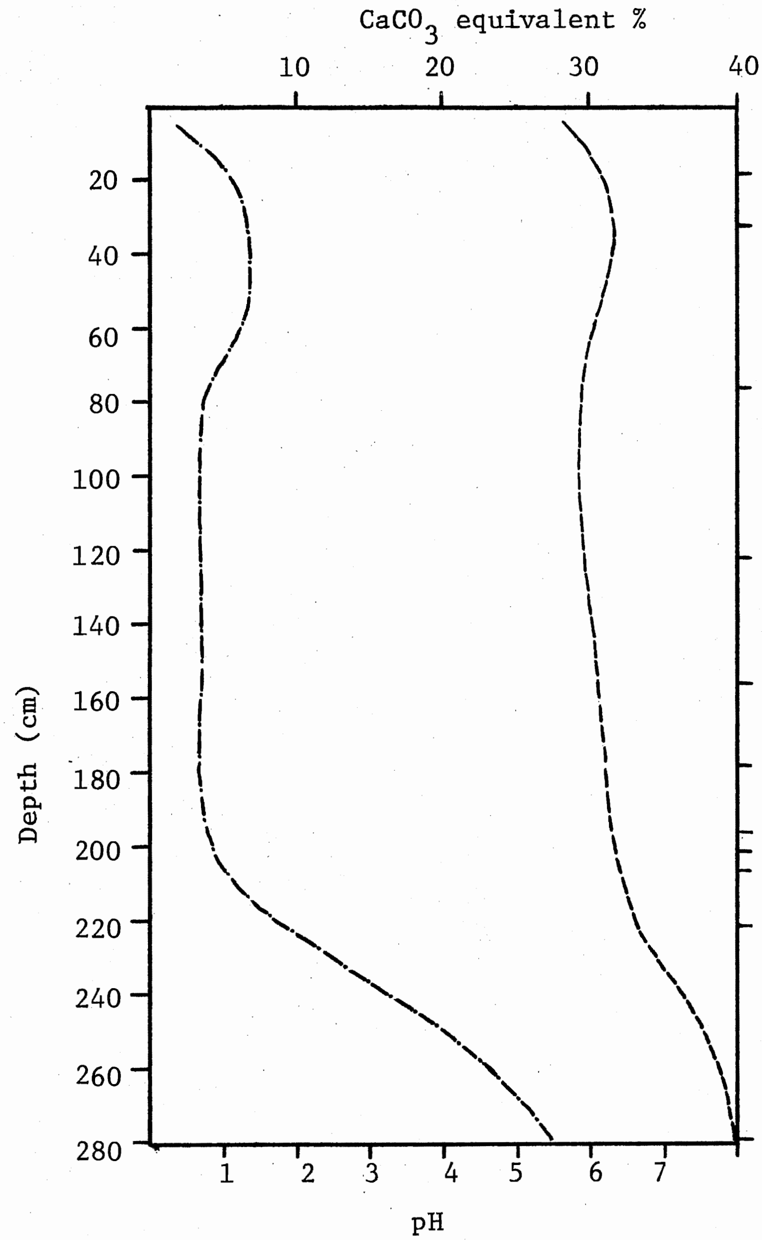

Figure 22. pH, calcium carbonate equivalent-depth distribution for Grandfield soil.

pH Measurement

pH values for Cordell soil (Table XI) reveal a very little difference between different horizons. The data show a gradual increase with depth. The surface horizon maintains the lowest value and C horizon is the highest. pH distribution in the B horizon is relatively equal and slightly increases in the transition zone towards C horizon (Figure 18).

While Cordell is low in calcium carbonate content, the vertical distribution of pH and the high base saturation suggests that this soil might be developing under xeric conditions. The little change in pH value exhibited between different horizons is a good indication of the low intensity of calcium carbonate and bases leaching for all horizons.

pH data distribution in Quinlan resembles its Cordell counterpart. A horizon has the lowest value. The pH is relatively constant with depth and no significant difference is exhibited between the lower part of B horizon and the transition zone (Figure 19). C horizon retains the highest pH value (8.0, 8.1). Calcium carbonate equivalent suggests that leaching intensity has been concentrated near the surface. This is reflected on the pH value measurement which indicates the slight change in the pH of the surface horizon and the absence of a significant difference between the solum and the parent material of this pedon.

pH value for Woodward indicates a slight change in the whole solum. The pH measurement for the solum ranges from 7.55 at the surface horizon to 7.92 at the lower part of the B horizon. The layer that separates between the lower part of the solum and the parent material shows a transitional value toward the C horizon pH remains constant in C horizon. The pH and carbonate distribution (Figure 20) is a good indication of the extent of calcium carbonate leaching which started to accumulate as a film of secondary deposit. Furthermore, the base saturation indicates some basic cations leaching.

pH data for Dill soil reveals a relatively sharp change between the solum and the parent material. pH values for the solum range from 6.4 to 7.3 and 8-8.4 in the C horizon. The data from calcium carbonate analyses indicates that the whole solum has been intensively leached (Figure 21). The development of the soft secondary calcium carbonates film at the lower part of the solum, the pH depth distribution, the relatively low base saturation, and the indication of the clay illuviation confirm the conclusion that this soil has been highly leached.

pH values for Grandfield indicate that this soil is acidic throughout the profile. The Ap horizon has the lowest pH value. No significant change (Figure 22) is traced between B and C horizon. The pattern of calcium carbonate distribution in addition to the low base saturation throughout suggest that the leaching of calcium carbonate has been negligible. This suggests that the parent material was low in base saturation at the time of deposition.

Leaching Intensity

Leaching of calcium carbonate has been considered one of the most important processes in the development of the soil profile. Recently it has been used as a criteria in classifying the soil (33). Leaching of calcium carbonate is a function of the amount of water moving through the profile, topography, and the texture of the soil. The degree of soil development could be determined by measuring the extent of carbonate leaching (30). The degree of genetic development of soil horizons increase with increased calcium carbonate leaching. Therefore, an index has been formulated to measure the extent of calcium carbonate leaching (30) which aid in locating the zone of maximum leaching.

$$\text{Calcium carbonate leaching index} = \frac{\text{maximum carbonate content below solum}}{\text{carbonate content in the horizon}}$$

The calculated index value for different horizon in each soil was plotted against depth as shown in (Figure 23, 24). The curves character reveal the difference in intensity of leaching between the studied soils and indicate the zone of maximum leaching.

According to the character of the different curves, the studied soils could be arranged in a sequence. Each soil in this sequence represent a stage which indicates the intensity of the carbonate leaching. The stages of carbonate leaching for each soil is as follows:

1. Calcium carboante index is uniform and equal for different horizon. No significant leaching could be traced in the profile. Grandfield could be placed in this stage (Curve 24).
2. Cordell soil: Depth distribution of the calcium carbonate leaching has begun with relatively low value of the carbonate leaching intensity. (Figure 23)
3. Quinlan soil: (Figure 23) Depth and distribution of the calcium carbonate index indicate that A has undergone the maximum amount of leaching.
4. Woodward soil: The carbonate leaching has advanced toward the subsoil to the middle part of the B2 horizon. The higher intensity of leaching of A horizon and of upper half of B2 horizon, the development of the secondary calcium carbonate films, permits this soil to be in a stage more advanced than Quinlan soil (Figure 23).
5. Dill soil: The carbonate leaching intensity index for this soil

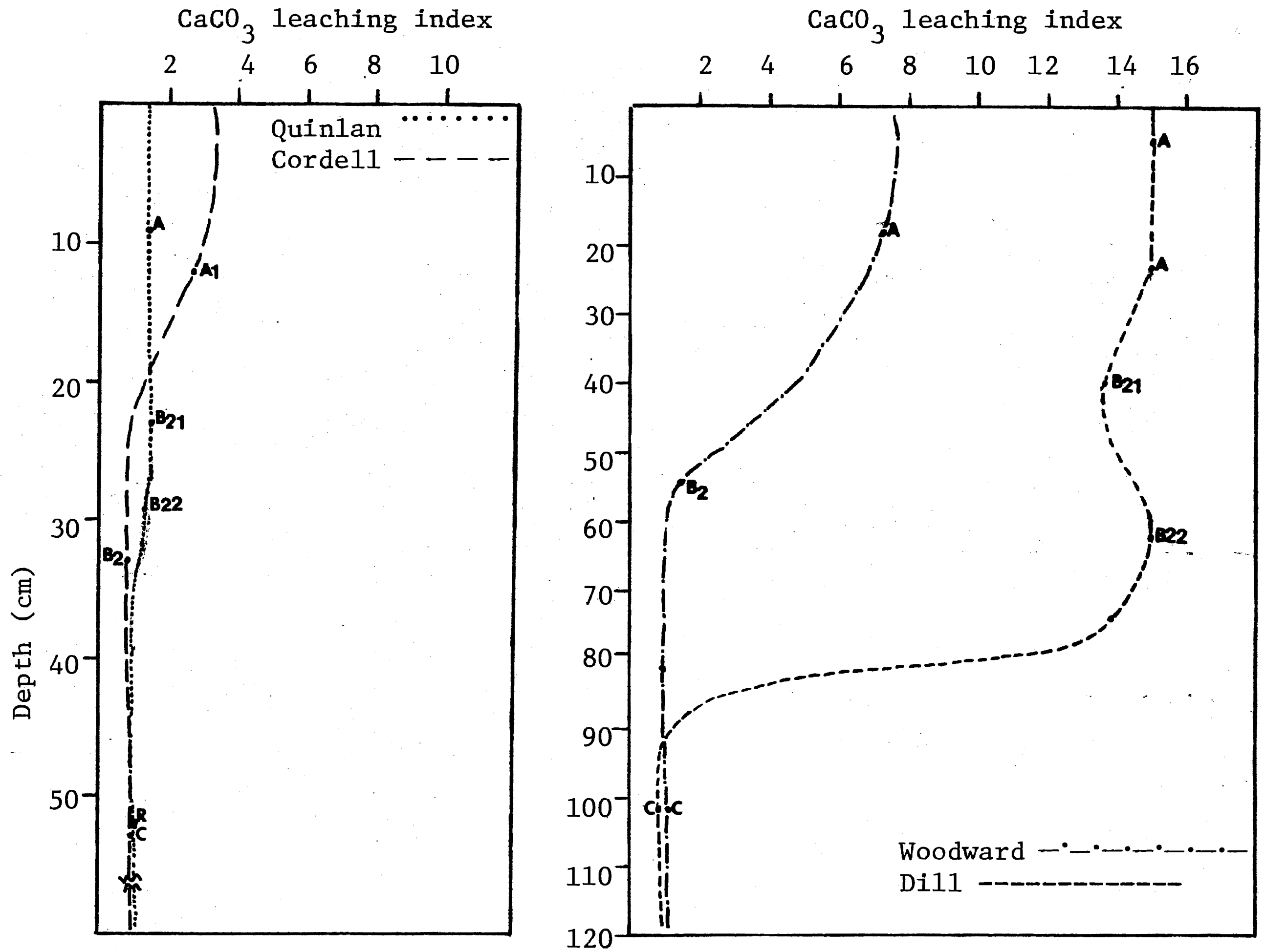

Figure 23. Calcium carbonate leaching intensity-depth distribution for Cordell, Quinlan, Woodward, and Dill soil.

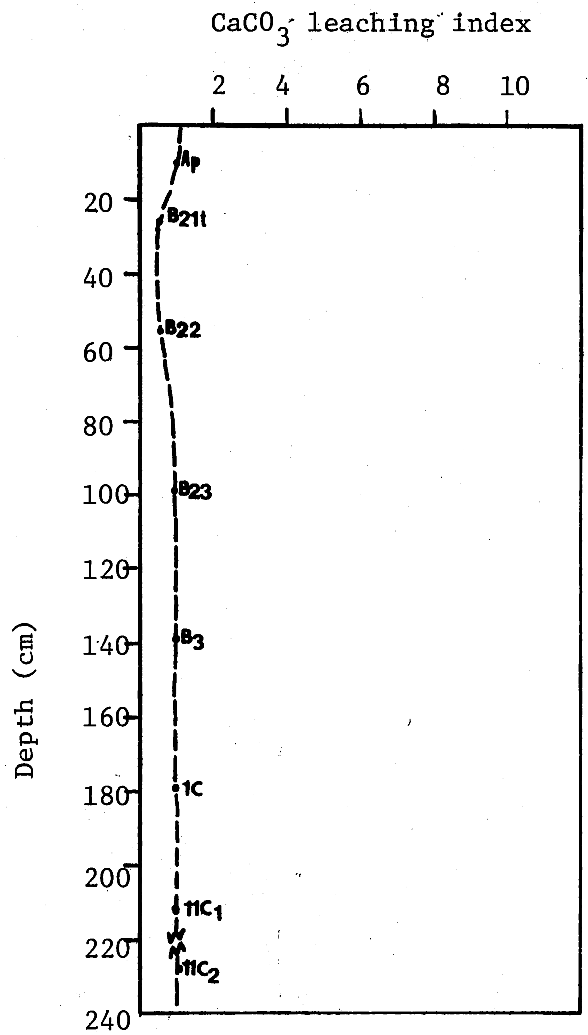

Figure 24. Calcium carbonate leaching intensity-depth distribution for Grandfield soil.

indicates that the entire solum has undergone an extensive leaching (Figure 23). This stage represents the most advanced stage of carbonate leaching among studied soil.

The intensity depth distribution of the calcium carbonate index reveals a close relationship between zone of maximum carbonate leaching, zone of maximum clay accumulation, and the limit at which fine clay illuviation could initiate.

Maximum clay accumulation at the surface and the increase in the total clay and fine clay toward subsurface follows the sequence established by calcium carboante leaching intensity. At the stage where carbonate depletion reaches a certain level, the fine clay illuviation becomes one of the soil formation processes that contribute to more prominant horizons development. It seems very obvious that the carboante level in Dill soil has reached this stage. This is confirmed from the particle size analyses which indicate that illuviation has started. Furthermore, though the calcium carbonate leaching intensity for Grandfield soil indicates a negligible amount of carbonate leaching, the argillic horizon has developed in this soil. This gives another indication that a limited or a certain level of calcium carbonate should be reached before clay illuviation can take place in the soil profile.

Organic Matter and Root Distribution

The quantity of organic matter occurring at various depths in soil are dependent upon a number of environmental factors. The most clearly related factors are probably rainfall and type of vegetation cover.

The organic matter data (Tables X and XI) in four pedons (Cordell, Quinlan, Woodward and Dill) show a distribution that characterizes the effect of grass vegetation on the pattern of organic matter accumulation. The organic matter content reaches its maximum value at the surface horizon and decreases gradually with depth.

In Cordell soil (Figure 25) A horizon contains 2.08 percent organic matter. This value decreases gradually with depth and level off in the transitional zone between B and C horizons. C horizon maintains the lowest amount of organic matter. The root distribution (Figure 25) for the same pedons follows the same pattern as the organic matter does. The number of the roots decrease more gradual in the transitional zone between B and C than above.

The organic matter depth-distribution for Quinlan soil (Figure 26) shows a gradual decline in the organic matter. A very small difference in the organic content is exhibited between A and B horizon. The organic matter content of the transitional zone (1.04%) is comparatively the same as the solum. C horizon (0.52%) contains the lowest amount. The relatively high organic content of the subsoil in the comparison to the surface content is a reflection of the deep penetration of the plant roots.

In Woodward soil (Figure 27) surface horizon contains the highest organic content (1.03%). The organic matter content decreases gradually with depth and is constant in the transitional layer between B and C horizon. At the same time, the roots distribution show a sharp decline between the lower part of the solum and the parent material.

In Dill soil (Figure 28) organic matter content for a horizon is 1.76%. This value decreases gradually from A to the lower part of the B horizon. Then it decreases sharply in the C horizon. This sharp contrast in the organic matter between the solum and the C horizon is

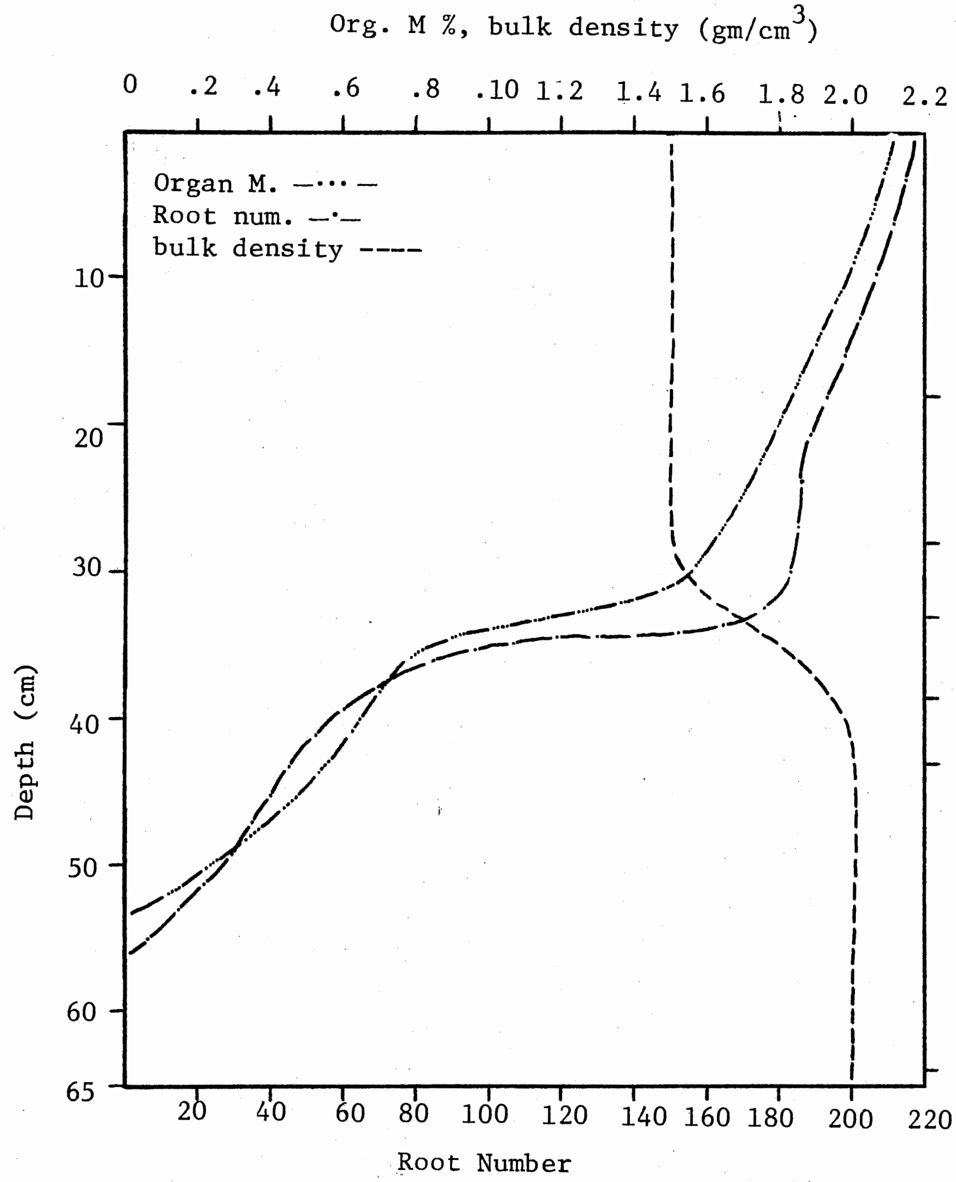

Figure 25. Roots number, organic matter, bulk density-depth distribution curve for Cordell soil (subsampled horizons).

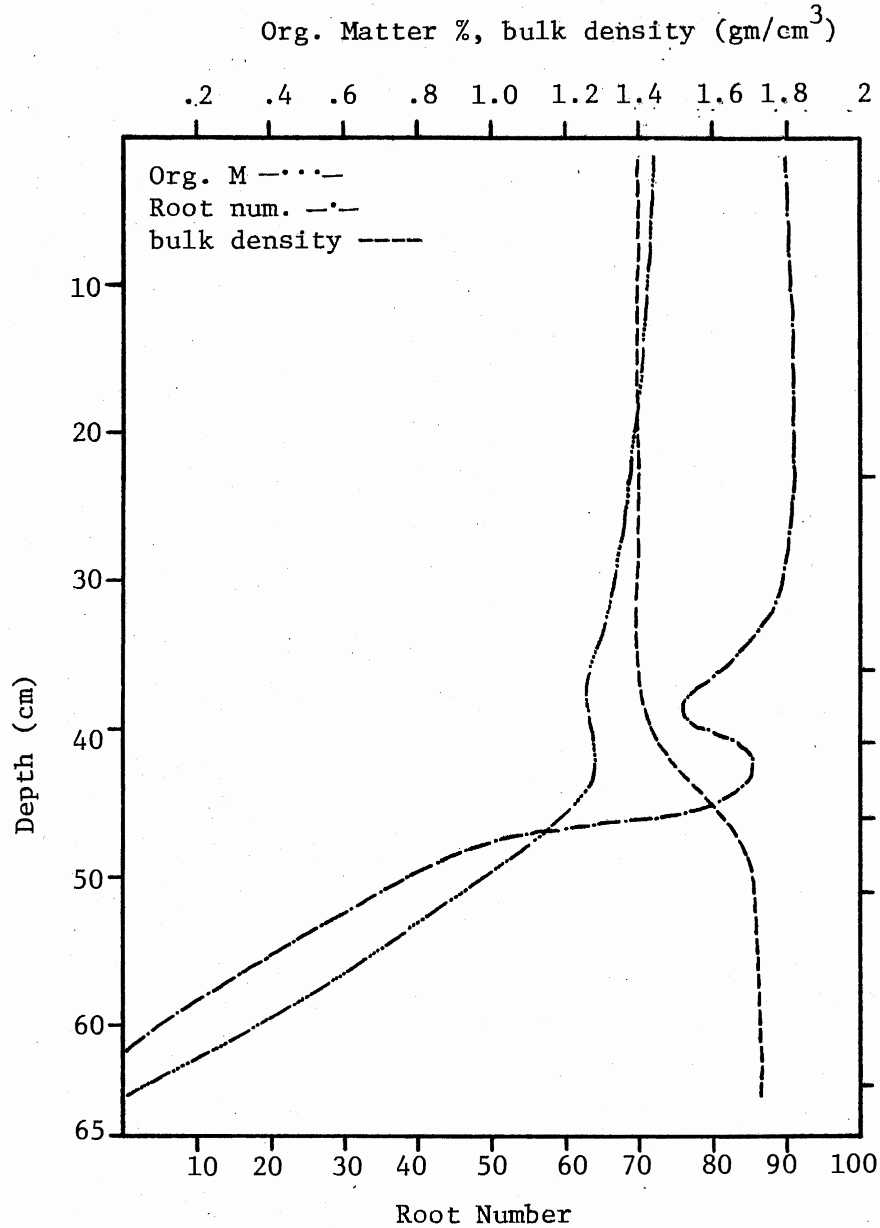

Figure 26. Root number, organic matter, bulk density-depth distribution curve for Quinlan soil (subsampled horizons).

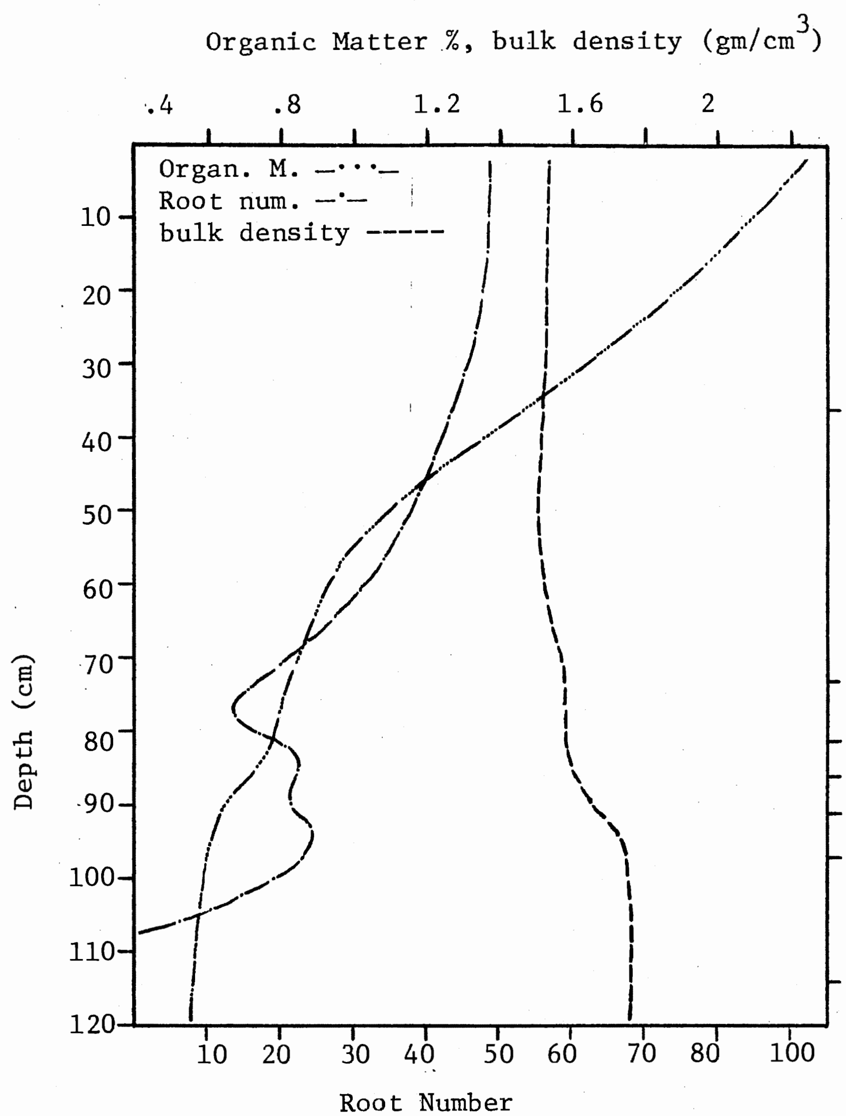

Figure 27. Root number, organic matter, bulk density-depth distribution curve for Woodward soil (subsampled horizon).

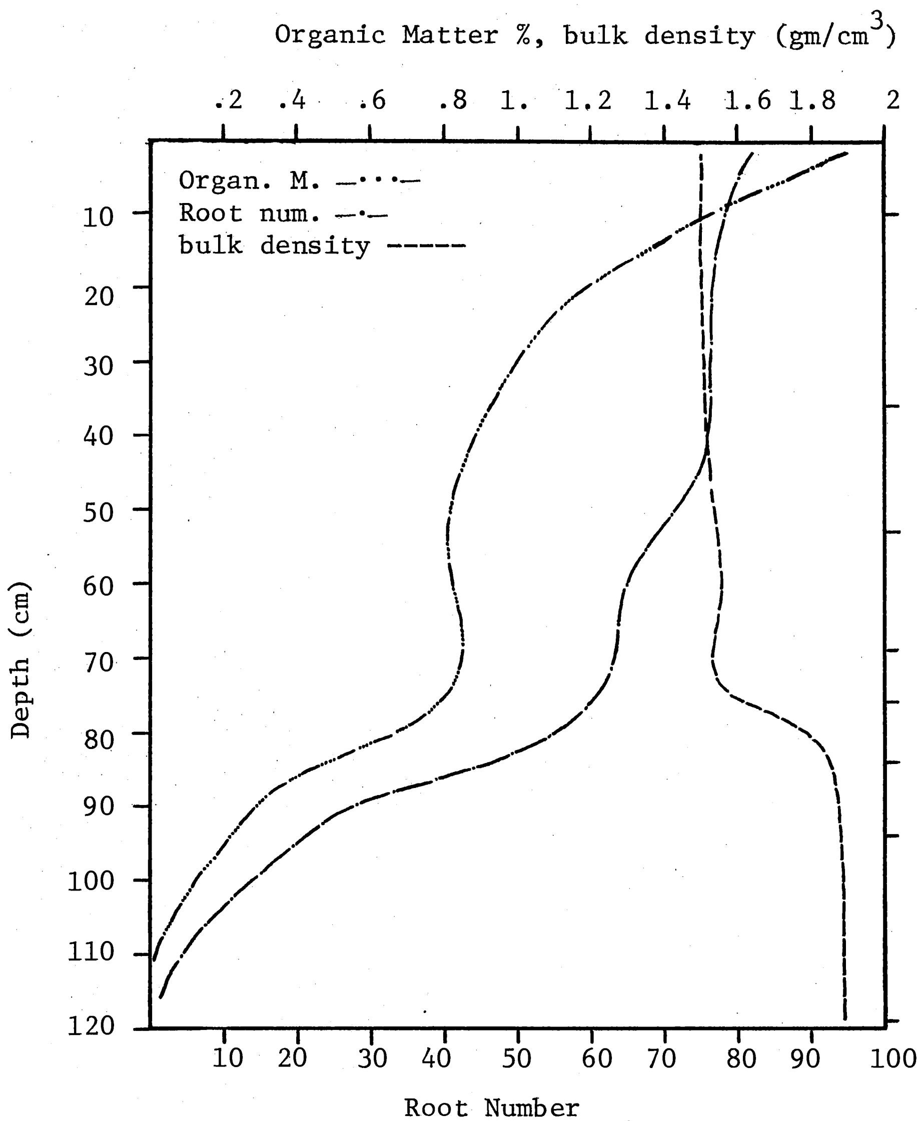

Figure 28. Root number, organic matter, bulk density-depth distribution curve for Dill soil (subsampled horizons).

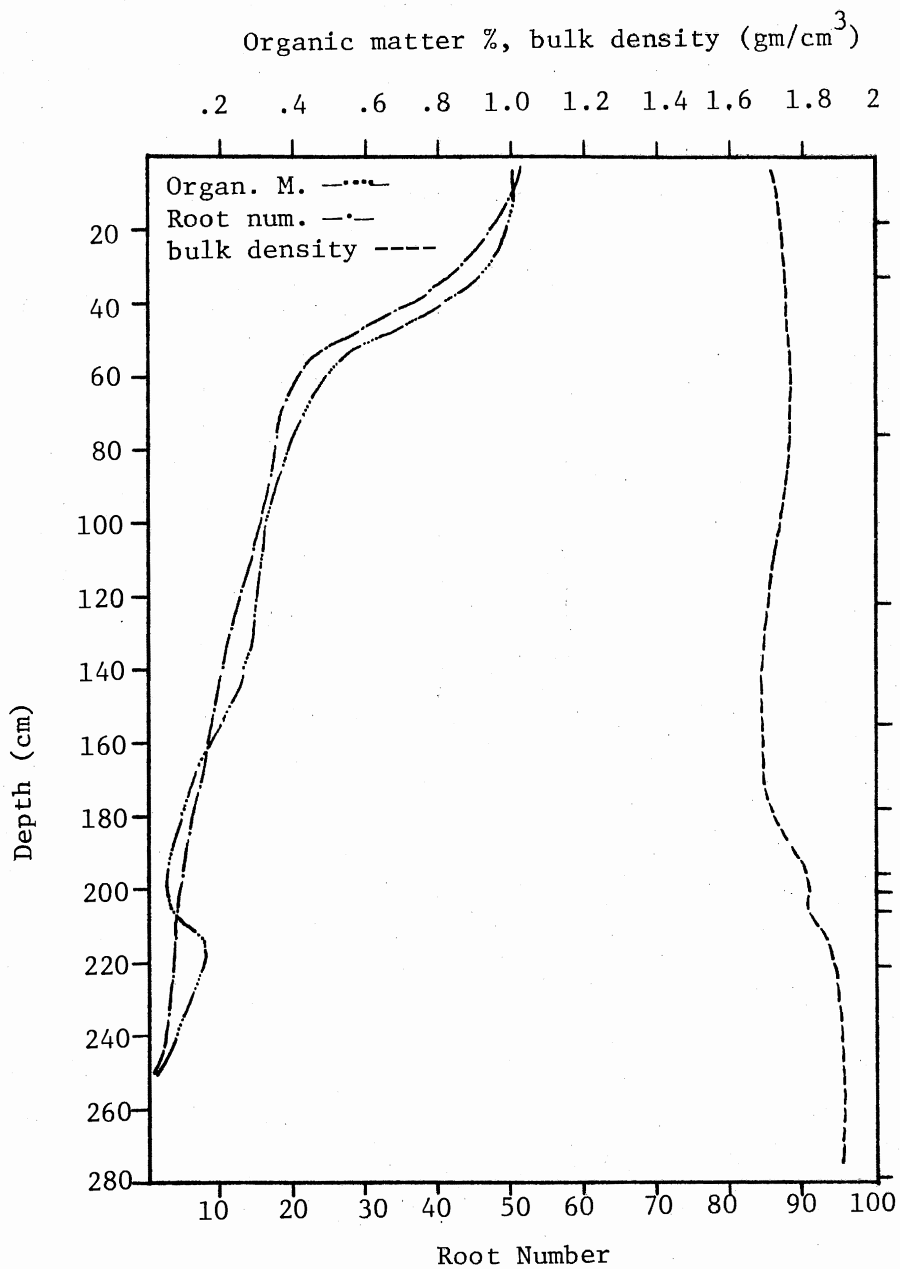

Figure 29. Roots number, organic matter, bulk density-depth distribution curve for Grandfield soil (subsampled horizons).

also exhibited by the root number distribution.

In Grandfield soil, the vertical distribution of organic matter content and the root distribution characterize the organic matter distribution in the soil that has been under cultivation for crop production purposes. Ap and B21t contain the highest amount of organic matter and the largest number of plant roots. Below B21t horizon (Figure 29) the organic matter content decreases gradually until it reaches the lowest value in the C horizon.

In all the pedons in this study, only one zone of maximum organic matter accumulation has been observed. This zone is located at the surface horizon of each pedon. No second maximum organic matter accumulation occurs below the surface indicating the absence of organic matter illuviation processes.

None of the studied soils met completely the requirements of mollic epipedon. This is either due to the lack of dark layer thickness with the appropriate chroma value or due to the lack of development of soft consistancy at the surface horizon, but organic matter percentage for the surface horizons in all soil meet the requirements set up for mollic epipedon.

Physical Measurement

Bulk Density

The change in bulk density indicates the presence of certain morphological properties and genetic processes. In this study, the bulk density was measured for subsampled horizons. There is a distinct tendency for the bulk density to increase with depth in all studied pedons. This apparently resulted from a lower content of organic matter, less aggregation and compaction caused by weight of the overlying layers.

According to the bulk density measurement, the soil profile could be divided to the following zones that could represent three different levels of bulk density value. They are: the surface and subsurface horizon, a transition zone, and the parent material.

The bulk density value increases very slightly with depth in the first zone for four soils; namely, Cordell, Quinlan, Woodward and Dill. In cordell soil, the bulk density ranges from 1.50 in the surface horizon to 1.52 at the lower part of the solum, 1.40 to 1.54 in Quinlan, 1.54 to 1.59 in Woodward and 1.52 to 1.57 in Dill soil. This zone exhibits different patterns in Grandfield. The bulk density in this zone increases from the surface and reaches the highest value in the argillic horizon where it again decreases toward the transition zone. This could be due to the slight increase in the fine clay in the subsoil horizon or compaction caused by the machinery used in cultivation.

The second zone represents an intermediate or transitional value between the solum and the parent material. The transition zone, which according to the field description is assigned to the soil solum, exhibits a value that is clsoer to the bulk density value for the C horizon, as in Cordell and Dill, or intermediate value between the solum and the horizon as in Quinlan and Woodward soils. In Grandfield, the bulk density in this zone is lower than above or lower layers.

The bulk density measurement was relatively constant in the parent material. Generally speaking, in all soil the bulk density in the solum differs from its counterpart in the parent material. The change in the bulk density between the solum and the parent material may be sharp as in Dill and Woodward, and is less sharp in Dordell and Quinlan or insignificant as in Grandfield.

Relationship Between Organic Matter and Bulk Density

(Figure 30) shows the relationship between organic matter and bulk density for all horizons in each soil. The curves characteristics reveal a close relationship between bulk density and organic matter. This relationship is close especially in the early stage of soil development where the organic matter (as a function of the biological activity) accumulates and operates on changing the bulk density at a rate faster and deeper than the chemical weathering.

In all studied pedons, the curves indicate that bulk density of the parent material does not decrease in response to any change in organic matter. This is natural due to the low level of biological activity in the parent material. The bulk density of the solum zone show a different relationship with organic matter content at a different stage of soil development. The curve character for Cordell soil reveals that bulk density for A horizon does not change as the organic matter changes, but it does increase rapidly as the organic matter content decreases in the zone between B21 and the C horizon. In Quinlan soil, the bulk density remains constant in A horizon and the upper half of B2 horizon and does not change as the organic matter increases while it increases sharply in the zone between B2 and parent material when organic matter decreases.

The independency of bulk density on organic matter at deeper depth in the profile is more accentuated in Woodward and Dill soil. The bulk density for the transition zone in both soil increases rapidly as the organic matter decreases.

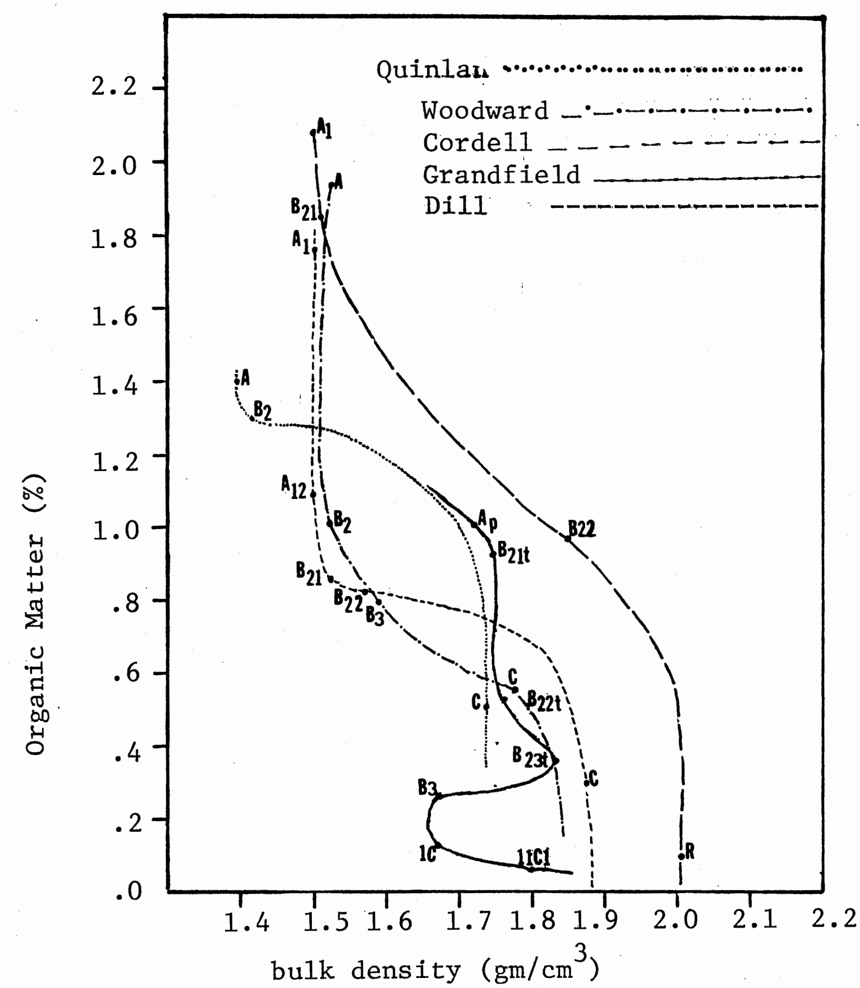

Figure 30. Relationship between bulk density and organic matter for Cordell, Quinlan, Woodward, Dill and Grandfield soils.

The curve that represents relationships between organic matter and bulk density for Grandfield indicates that bulk density depends on other factors besides the bulk density. The curve shows a slight increase in the bulk density as the organic matter decreases. In addition to that, the argillic horizon has higher bulk density values than the parent material. This could be due to the higher clay content especially the fine clay of this horizon or to the compaction caused by machine especially on the surface horizon.

Generally, it is noticed that less bulk density response to the change in organic matter content is observed in the zone of maximum clay accumulation. The thickness of this zone differs from one soil to another. Namely, A1 and top of B21 in Cordell soil, A and half of B2 in Quinlan, A, B2 and half of B3 in Woodward, A11, A12, B21 and half of B22 horizon in Dill and B21t, B22t and B23t in Grandfield soil. The explanation of this could be based on the idea that first interaction between organic matter and bulk density occurs at the surface horizon. This is natural due to the fact that organic matter accumulation starts at the surface layers. At early stages of soil development, any increase in organic matter causes a change in bulk density. As the weathering becomes more intensive and acts deeper in the profile, the zone (solum) that has undergone more chemical and physical weathering shows less response to the change in organic matter content. Possibly, except the transition zone where the weathering is still very weak. The bulk density in this zone increases gradually in response to the change in organic matter content as in Cordell and Quinlan soil. As weathering processes advances deeper and more intensive, over a long time, the bulk density in the relatively more advanced weathered soil starts responding to another factor and only the transition zone shows response to the organic matter content. This is substantiated by the fact that weathering diminishes with depth and that the bulk density maintains its close relationship with organic matter content. Furthermore, in Grandfield, where the soil development has reached a stage satisfactory to establish an argillic horizon, the bulk density measurement for this soil does indicate that it depends on another factor like accumulation of clay rather than an organic matter accumulation only.

Soil Color Development Equivalent

The color of the soil is measured by three variables: hue, value and chroma (35). Value appears to be connected with alteration of parent material associated with distribution or organic matter. While hue and chroma appear to be more closely related to the stage and intensity of the parent material.

If the hue and chroma are used separately for assessing the color development, the area of maximum profile development doesn't occur when the hue is the reddest or when the chroma is the strongest, but in between these two extremes.

Therefore, soil scientists (3) suggest a method of using the chroma and hue together to study the soil color development as related to the soil profile development. In this method, the hue is given a code number. The magnitude of the code number increases as the redness of the color notation increases as follows:

Hue	10R	2.5YR	5YR	7.5YR	10YR
Code	7.0	6.0	5.0	4.0	3.0

The code number for the hue was multiplied by the mean of the dry and

TABLE XII

COLOR DEVELOPMENT EQUIVALENT FOR CORDELL, QUINLAN, WOODWARD, DILL AND GRANDFIELD SOILS

Horizon	Depth cm	Color	CDE
	-----Cordell-----		
A1	0-18	2.5YR/4	24
B21	18-28	2.5YR/4	24
B22	28-36	2.5YR/4	24
R	36-64	2.5YR/6	36
	-----Quinlan-----		
A1	0- 23	5.0YR/4	20
B2	23- 43	2.5YR/4	24
C	43- 64	2.5YR/6	36
	-----Woodward-----		
A1	0- 36	5.0YR/4	20
B2	36- 74	2.5YR/6	36
B3	74- 89	2.5YR/6	36
C	89-114	2.5YR/6	36
	-----Dill-----		
A11	0- 10	5.0YR/4	20
A12	10- 36	5.0YR/4	20
B21	36- 53	2.5YR/4	24
B22	53- 84	2.5YR/4	24
C	84-119	10.0YR/5.5	16
	-----Grandfield-----		
AP	0- 18	5.0YR/3	15
B21t	18- 33	5.0YR/4	20
B22t	33- 76	5.0YR/4	20
B23t	76-122	2.5YR/6	36
B3	122-155	2.5YR/6	36
IC1	155-203	5.0YR/6	36
IIC1	203-221	2.5YR/6	36
IIC2	221-279	2.5YR/6	36

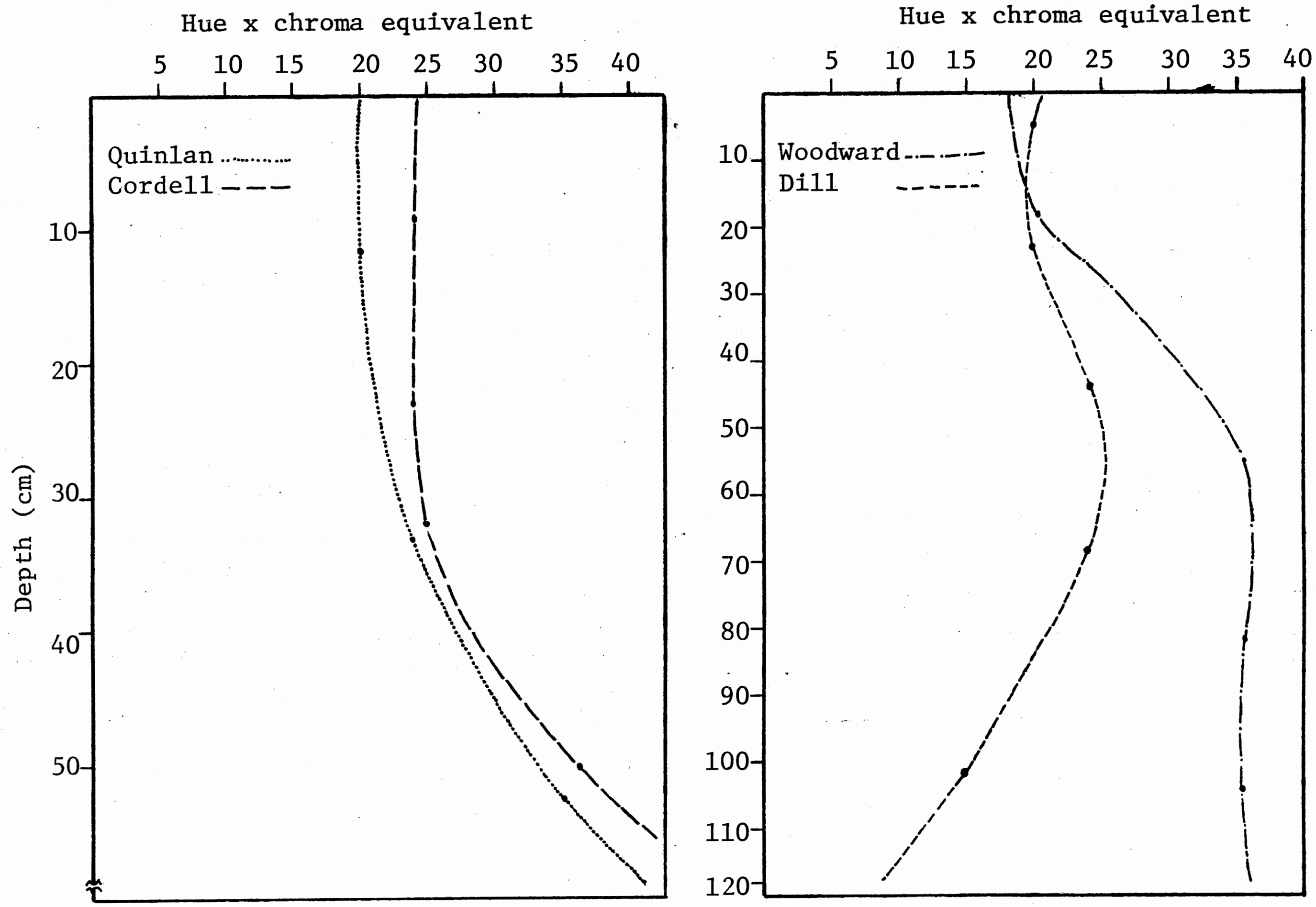

Figure 31. Distribution of the color development equivalent for Cordell, Quinlan, Woodward and Dill soils.

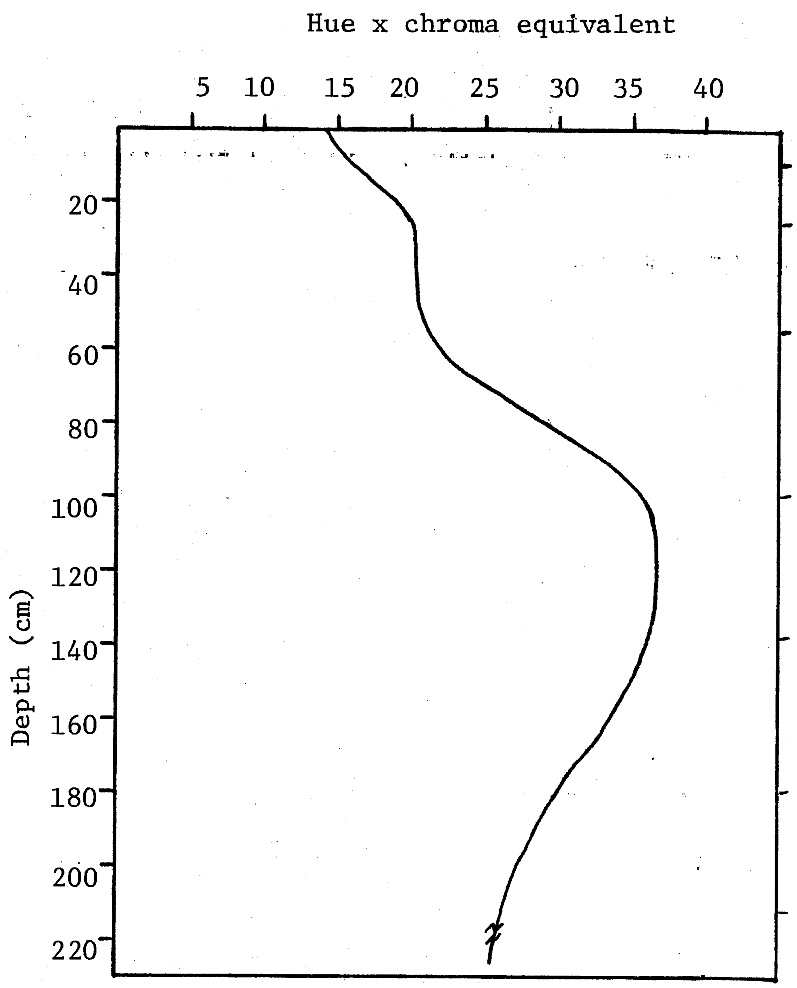

Figure 32. Distribution of color development equivalent for Grandfield soil.

moist chroma measured in the field (Table XII) on ped face and the ped interior. Crushed samples were used when peds were not available.

The values resulted from multiplying hue code value and chroma are plotted against depth for each soil (Figures 31, 32). The color development curve indicates strong resemblance in characteristics of color development curve for Cordell and Quinlan in one group and Woodward and Dill soil in another.

Considering area of maximum color development and amount of color development departure from the parent material, Cordell and Quinlan soils show no significant departure from the parent material. This indicates nothing than the influence of the organic matter. The color development for Woodward shows a slight color equivalent departure from the color equivalent of the parent material. This color equivalent departure becomes more significant in Dill soil and more obvious in Grandfield soil.

If the color development curves for the studied soil considering the shape of the curve, the magnitude of the maximum and minimum color development, and thickness of the zone of maximum color development were to be used in evaluating the extent of the genetical development of each soil. The soils could be arranged as follows: Cordell, Quinlan, Woodward, Dill and Grandfield. Starting from the least to the most developed soil. The confirmation of this finding is provided from both mechanical analyses concerning the zone of maximum clay accumulation and calcium carbonate leaching which suggests a similar arrangement.

The Soil Lower Boundary

Soil as defined by soil scientists has resulted from the integrated effect of the chemical, physical and the biological weathering. This implies that the zone which we call solum should be ultered by many factors. The intensity of each of these factors differ from place to another (32). In the arid zone, the biological factor is the weakest, while the physical factors are the strongest. In tropical zones, the biological and chemical weathering dominate. Holding this view, it is possible to find a situation where the chemical weathering operates deeper and more intensive than the biological or physical weathering. Therefore, the zone of chemical, biological and physical weathering may not coincide at the same depth in the solum (22).

In soil morphology studies, the pedon description provides the first basic information about the genesis of the soil. The properties that are reflected on the soil morphology are the ones which aid in the distinction between the solum and the parent material. These properties result from the differential change of the color, texture, structure. Thus, if the weathering is strong and has been functioning on the soil for long times, these properties become very well expressed in the soil profile and could be used to locate the boundary between the solum and the parent material. Therefore, in weakly developed soil, it is expected that these properties are not strongly expressed on the soil morphology.

In this study, five soils were selected. The physical, chemical, and morphological properties of these soils were measured to investigate the possiblity of using a criteria to aid in placing the soil lower boundary.

Calcium carbonate leaching was investigated and was related to the area that reflected color, structural or textural differences. The carbonate data and the leaching index indicate that the Cordell, Quinlan and Woodward soil only the upper portion of the solum was leached. No morphological features that could be related the depth of the carbonate leaching were observed in these soils. Furthermore, the calcium carbonate data do not show any major break in the soil profile. According to the hypothesized genesis of these soil, Dill soil is the most developed soil next to Grandfield soil. The calcium carbonate leaching in Dill soil exhibits a sharp boundary between the solum and the parent material. This boundary coincides with a change in color, strucure, and texture differences. Therefore, it is not possible to use the depth of calcium carbonate leaching to be the soil lower boundary in young soil unless the carbonate leaching has reached an advanced stage, which in turn, allows another soil formation process to take place in the soil profile.

Base saturation also follows the calcium carbonate distribution since both are functions of the amount of the downward movement of the water. Thus, this criteria also is not a good property to be used in locating the soil lower boundary in weakly developed soil.

The soil color development was also investigated. No significant color change due to soil formation process was traced in Cordell, Quinlan, and Woodward soils. The color development equivalent which is a function of chemical and biological weathering shows some development in the solum of Dill soil. This is due to advanced stages of calcium carbonate leaching and development of strong cambic horizon. At the same time, Grandfield show the strongest color development. This is due to advanced stage of soil development. Furthermore, the color development equivalent curves did not show a significant change in the soil profile of Cordell, Quinlan, and did not show a major change in other soils in the area between the solum and the parent material. In this study, a good relationship exists between the bulk density and the organic matter. This relationship even holds in early stages of soil development which is represented mostly by Cordell and Quinlan soil. At this stage of soil development the chemical weathering is weak and function less intensively at lower depths than the biological factor. This is due to the fact that calcium carbonate should be removed first to allow more active chemical weathering at a deeper depth. As the carbonate is leached deeper in the profile, as in Dill soil, the bulk density starts to be dependent on another factor like caly accumulation rather than organic matter alone. When the carbonate is totally removed from the profile, the bulk density becomes more dependent on clay accumulation rather than on organic matter as in Grandfield soil. Nevertheless, in all studied soil, the soils profiles exhibited a transition zone where the bulk density changes was dependent on the organic matter. These zones were the zones of the lowest chemical weathering, but the thickness of this transition zone becomes less as the soil development becomes more advanced.

Thus, the bulk density is the first property to be changed in the soil at the early stage of soil development that could be traced in the field. At the same time, the depth that shows change in bulk density coincides with depth of organic matter accumulation. Furthermore, this boundary becomes more clear as other factors operate more actively. Therefore, bulk density could be used as criteria in locating soil lower boundary at early stages of soil development.

CHAPTER X

Summary and Conclusions

1. In weakly developed soil formed in calcareous material and high base saturation, the depth of calcium carbonate leaching and the base saturation are not good criteria for placing the lower boundary of the soil because only partial leaching and low base saturation occur only in horizons having a significant clay accumulation.
2. In the same soils, it is not possible to use the color criteria in placing the lower soil boundary because no color change was observed in the profile of these weakly developed soils. However, some color change was observed in more developed soil, but no sharp change could be traced in these soils.
3. Organic matter and bulk density interaction indicates that the bulk density is the first property to show a major change in the profile of the weakly developed soil. The study indicated by the bulk density changes is more accentuated as the soil development advances. Therefore, bulk density could be used in placing the soil lower boundary in the profile of weakly developed soils. Nevertheless, to rule out the applicability of the bulk density as a criteria in locating the lower boundary of the solum in soils that exhibit similar stages of development, further investigation should be conducted on soils under different conditons.

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