CLAY DEPOSITION IN SOIL AND ITS EFFECT ON
PLANT GROWTH AND NUTRIENT UPTAKE

by
Houcine Layachy Malek

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1967
STATEMENT BY AUTHOR

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SIGNED: Hozine Malek

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

D. D. Evans

Professor of Soil Physics
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- **LITERATURE CITED**
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INTRODUCTION

Clay illuviation or clay migration within a soil profile occurs because of the fact that clay is the smallest particle in soil (less than two microns) and also is slightly soluble in water. Under downward movement of water through soil, clay particles and dilute solutions of ions directly from the weathered clay in the surface horizon may be carried by the percolating water to the subsurface where they may be concentrated and, hence, deposited.

The occurrence of clay deposition may be of considerable importance to several aspects of soil science. For instance, it may affect: (1) soil texture, (2) soil structure, (3) soil porosity, (4) infiltration rate, (5) drainage, and (6) microbial activity. Therefore, once these properties of the soil are affected by clay deposition or clay accumulation, the environment of the plant roots may become greatly altered.

The objective of this study was to determine and present some of the fundamental roles that clay deposition or clay accumulation plays upon plant growth and nutrient uptake under natural conditions. In order to fulfill this objective, as it nearly would be under field conditions, a soil material possessing clay deposition was used. To
this soil material, additional clay accumulation was made artificially by leaching pots with a two per cent clay suspension before growing wheat plants. For this reason, experimental laboratory and greenhouse experiments were developed to provide data on: (1) the rate of growth of tops and roots of wheat plants; (2) the differences in nitrogen, phosphorus, and potassium accumulation in plants between the control and treated soil; and (3) the correlation of plant growth and nutrient uptake.
LITERATURE REVIEW

Clay may be defined in soils as those particles less than two microns in size. However, the word has a popular and also a series of technical meanings, which are useful but not identical. Hence, a farmer's or soil scientist's concept of clay may be rejected by a potter, a brick manufacturer, a judge, or a ceramist.

In the popular sense, clay is a finely-grained rock which becomes sticky when wet. Potters and ceramists apply this term to substances which are plastic or which can be made plastic by suitable treatment and the addition of water. Chemists and physicists define clay as an admixture of certain mineralogical species; such a concept is both convenient and valuable, but may be misleading in some instances. A concise definition of clay by the American Ceramic Society is as follows: "Clay is a fine-grained rock which, when suitably crushed and pulverized, becomes plastic when wet, leather-hard when dried and on firing is converted to a permanent rocklike mass" (38).

Geologically, clays are composed of various minerals of primary and secondary origin, all of which are of a comparatively "fine" or small grain size. Clays in their natural form may consist of many different minerals, not one of which predominates. There are, however, certain
minerals or classes of minerals which occur in some clays and have been termed clay minerals.

Soil forming processes cause the reorganization of soil constituents by weathering of mineral and by translocation of the more mobile constituents. These processes result in producing the different soil profiles with their distinct physical, chemical, and biological features.

The inorganic portions of soil materials are usually composed of particles with a relatively complete size distribution from the extremely small to something at least two millimeters in diameter. The smallest size fractions in this range (less than two microns) are clay particles. Clay particles do not only form and modify in the soil but they are also being moved from the upper horizons to the lower horizons of the soil.

A soil horizon may be defined as a layer within a soil that is approximately parallel to the soil surface and which has properties that are produced by soil forming processes but which are unlike those of adjoining layers (48). Mobility and movement of clay minerals in the soils, from the upper horizons to the lower ones, take place by means of three different processes, called soluviation, cheluviation, and dispersion. The first two processes, soluviation and cheluviation (44), are responsible for eluviation of the decomposition products of clay minerals from the upper to the lower horizons of the soil.
Decomposition of clay minerals is carried out by the different processes of weathering (physical, chemical, and biological), which result in producing a wide variety of inorganic compounds (8). Both the quality and quantity of the decomposition products vary according to the type of minerals and climatic and biochemical conditions (8, 18, 19). The relative rate of movement of the decomposition products of the clay minerals was found to be controlled by the aforementioned processes, i.e., soluviation and cheluviation, which act together but independently. Soluviation means the removal of soluble cations from surface to lower horizons while cheluviation is the removal of Al₂O₃ and Fe₂O₃.

The third process (dispersion) is responsible for the percolation of finely dispersed soil fractions (suspensions). This process is of great interest to soil scientists in relation to the theory of the development of illuvial horizons (hard pans and clay pans) in acid and Solonetz soils (1). Podzolic soils with an illuvial horizon having a clay fraction similar in composition to the clay of the other soil horizons, including the eluvial horizons, have been discovered in recent years. From this, it has been concluded that the illuvial horizon in these soils has developed by the infiltrational movement of clay from the eluvial horizon (37).
The processes of eluviation and illuviation give rise to horizons: namely, eluvial horizon and illuvial horizons. All of these terms are defined by Buol and others (12, 15, 48, 49) as follows:

**Eluviation**: Removal of soil material from the upper to the lower horizon in solution or in colloidal suspension.

**Eluvial horizon**: Soil horizon from which fine material has been removed either in solution or water suspension.

**Illuviation**: The process of deposition of soil material removed from one horizon to another horizon of the soil, usually from an upper horizon to a lower horizon in the profile.

**Illuvial horizon**: Horizon that has received material from some other part of the soil.

In order for clay particles to move in the soil they must be in the form of a very dilute and stable suspension (8, 11). Accordingly, movement of the clay suspensions through the soil profile was found to be affected by:

1. Clay mineral type (19, 21)
2. Amount of percolating water (14)
3. Organic matter and soluble salts content (5, 19, 22, 39, 37)

The downward movement of both decomposition products of clay and clay suspensions takes place through the soil pores (voids). Nothing is known at present concerning the size of voids through which particles of particular size and shape
will pass in suspension, but experience suggests that illuviation Argillans (clay films) are usually associated with voids that can be seen under the microscope at magnifications up to 800x. However, illuviation of clay films from soluble materials may be associated with smaller voids.

Regarding the decrease of the downward movement of clay suspension and its deposition, it was found that most of it accumulates in the lower B and upper C horizons. Some factors were found to be responsible for creating this illuviation zone in the soil profile, such as desiccation, electrolytes, soil texture, and drainage. The continuous movement of clay minerals, eluviation from the upper horizons of the soil profile and its deposition (illuviation) in the lower horizons and/or its removal in the drainage water may affect the different characteristics of the soil profile, such as color, texture, structure, and chemical composition. Although many of these characteristics are easily observed on a macro scale, micro chemical heterogeneity resulting from such movement has been demonstrated. The influence that such micro heterogeneity has on plant growth has not been demonstrated.

To summarize, there are two mechanisms involved in the downward movement of clays by water. They are:

1. The movement of clay as true chemical solution which is simply the separation of soil components into
ions as a result of weathering. Upon their final rest, these ions may recrystallize and thus, form or reform clay minerals, the type depending on the environment.

2. The movement of clay as a suspension. It is the transport of clay particles through the soil profile. In this case, the type of clay is found to be of identical chemical composition in the profile. This vertical translocation of clay in the profile is also known as illumerization (12).

The greatest deposition of clay occurs in the B horizon. In the new classification system (48) this particular horizon is termed as an Argilllic horizon. It is an illuvial horizon in which silicate clays have accumulated to a significant extent.

Investigators of clay accumulation in the B horizon of soils have proposed two principal mechanisms which may account for this accumulation: (1) formation of clay in situ, and (2) movement of clay downward from the upper horizons. Both field and laboratory observations and experiments have substantiated these two proposals qualitatively but scarcely quantitatively. Good quantitative measurements of clay accumulation are not available. In fact, Buol (11) holds that such data are unattainable and will continue to be so until the interacting chemical and physical processes can be measured independently.
Clay accumulation in the B horizon appears in many forms, "clay pans" and "clay skins" (11). "Clay pans," as defined, are compact horizons or layers rich in clay and separated more or less abruptly from overlying horizons (49). Horizons that are high in clay content, either because of illuviation or by inheritance from clay-rich parent material, but are not separated abruptly from the overlying horizon, are not universally considered to be "clay pans," although some authors refer to them as "clay pans." A number of authors, Whiteside (46), and Whiteside and Marshall (47), have attributed some clay pans to clay formation in situ.

Clay skins may be defined as coatings of clay on the surfaces of root channels or structural units mainly in the B horizon. Some of the mechanisms involved in the formation of clay skins and clay pans may be the same. It seems most unlikely that only one mechanism is involved (11). The term clay skins is not always precisely defined and the use of the term varies from author to author. The result is confusion. Clay skins are variously called clay films, clay flows, tonhaütchen, oriented clays, cutans, and other foreign terms (30).

Some research workers gave different names to clay skin formations. In papers by Feofarova (16), Romashkevich (35), and Starykh (43), optically oriented clays are described as "secondary clays." Foreign authors have used
the designations "striated," "incrested," "ribbon-shaped," and most often, "optically oriented clays" (30).

Optically oriented clays occur in different types of soils. They consist of aggregates of individual clay particles all possessing the same orientation. In polarized light such an aggregate behaves as one crystal, for which it is possible to determine the index of optical refraction, the birefringence and other optical constants.

Optically oriented clays are easily detected in thin sections of soil samples with undisturbed structure under crossed Nicol prisms with simultaneous or periodic extinction. Optically unoriented clays are not visible when the Nicol prisms are crossed (30).

Accumulation of optically oriented clays in various soils differs not only quantitatively but also with respect to form, dimensions, and orientation with respect to other soil components.

Optically oriented clays in soils were first discovered and described by Polynov (33) in thin sections of "orstein" producing horizons of gray sandy soils. Since the time pedological features were first identified, many researchers have devoted their work to the mechanism, genesis, and causes responsible for their synthesis. In the past, optically oriented clays in soils have been related to soil genesis and classification.
The mineralogical nature of the optically oriented clays of the soil has not yet been fully clarified. Thermal and X-ray analyses of soils containing an abundance of optically oriented clays show a preponderance of beidellite (30). Parfenova and Yamilova (32) found this to be iron beidellite. Popov (34) observed optically oriented clays in samples consisting of montmorillonite. He noted that kaolinite does not provide such formation. His investigations show that the character of the clay habitus is strongly affected by the absorbed cations, specifically that clay saturated with calcium for anisotropic aggregates of rectangular isometric shape. In water they neither expand nor lose their anistropy. Sodium saturated clays form odd-shaped aggregates which are anisotropic when dry but which swell, disintegrate and lose their anisotropy when wet. We may consider that optically oriented clays can be formed by montmorillonite, beidellite, illite, minerals of the polygorskite group or by other highly dispersed minerals (30). It is generally known that aggregates of oriented particles can easily be formed from individual particles of clay. The orientation is caused by the flaky shape of these particles: on sedimentation they tend to occupy the most stable position possible so that they all lodge in one plane. On the basis of his own investigations, Popov (34) concluded that clay particles may become oriented under the influence of surface tension. Other investigators
have noted this factor. The surface tension of water may prove to be one of the important causes in the formation of the incrustational forms of optically oriented clays.

Brewer (6) considers the alternate wetting and drying to be the principal cause of the orientation of clay particles formed in situ by the weathering of rock. Here, too, the influence of surface tension is also evident. Optically oriented clays are also formed under the influence of mechanical pressure. This phenomenon is known to petrographers from sedimentary rocks, and Popov (34) carried out appropriate experiments on it. Under the natural conditions of soil formation this process is evidently not important. The orientation of clay particles in soil takes place in general under the influence of surface tension and with periodic alternate wetting and drying. Mechanical pressures may be important as a factor in the formation of optically oriented clays when the soils are tilled, because of the effect of the tillage implements.

Clay skins were reported by Brown and Thorp (10) to occur in certain Grey Brown Podzolic soils in Indiana and Michigan. Frei and Cline (17) reported clay skins in several Grey Brown Podzolic soils of New York State. Several workers have observed and reported clay accumulations resembling clay skins in Planosols. Brown and Thorp (10), Kunze and Oakes (25), Retzer and Simonson (36) in California.
Clay skins were reported from certain Latosols in the Congo by Kellogg and Davol (23). In describing Red-yellow Podzolic soils, McCaleb (28) noted some skins in the lower A₃ horizons and more developed ones in the B₁ horizon. The clay skins were reported to attain their maximum thickness on the vertical pores and root channels in the B₂ horizon, although more total clay occurred only on "tongues," whose positions were apparently controlled by rocks and large channels. Matelski (27) described clay skins in some Brunizem soils of Nebraska.

Many researchers have concluded that clay could be moved in dilute suspension from the surface horizons and precipitated at the lower reaches of the wetting front to create a clay enriched B horizon. In Australia, Brewer (7) concluded that there was no doubt that the strongly oriented clay layers he found coating unusually large pores were deposited from clay suspensions. Jenny and Smith (22) formed artificial clay coatings on glass beds. Brewer (6) was able to produce the oriented clay deposits by passing dilute clay suspensions of approximately 60 per cent illite and 40 per cent kaolinite and a little quartz through a sand column or when the sand columns were wet by capillarity. The same formations were observed regardless of the dominate cation thus indicating that process was physical and independent of chemical flocculation. Buol and Hole (13) found that when using dilute clay suspensions obtained
from leaching columns they could produce clay skins by allowing the suspensions to wet unweathered loess samples which were alternately dried in a Buchner funnel under suction from a water aspirator. In their experiment they used the same loess material to collect the clay suspension and as matrix to form the clay skin, thereby eliminating chemical differences. As few as 10 wetting and drying cycles produced clay skin deposits. From these results, it can be concluded that only partial desiccation, approximately that obtained by actively transpiring plants, is necessary for stopping the clay movement in the B horizon (13).

Although clay skins can be taken as evidence of clay illuviation, their absence should not be taken as proof of the lack of illuviation as pointed out by Buol and Hole (13). The clay skin structure is seen to be destroyed in the soil by various proisotropic processes: namely, by the churning action of wetting and drying clay (Grumusol, for instance, or intisols). Therefore, it is common to find a soil with a high content of clay in the B horizon that does not have optically oriented clay structure present.

Optically oriented clays are also referred to as cutans. The term cutans is proposed for a broad group of Pedological features, including so called "clay skins," associated with the surfaces of the skeleton grains, peds, and various kinds of voids within soil materials (7). The
chief differentiating characteristics of cutans are the kind of surface with which they are associated, the mineralogical nature of the cutanic material, and the fabric of the cutans themselves. Cutans can be interpreted on the basis of their characteristics in terms of the genetic processes of soil formation, and classified into simple and compound groups, each of which can be subdivided into illuviation, diffusion, and stress types, composed of particular materials. The effects of cutans on profile development and plant growth may be considerable and their characteristics may dominate the characteristics of the soil material.

In recent years the terms, "clay skins" and "tonhäütchen" have been used to refer specifically to both "skins" and "clay." They have a strong genetic inference indicating that the surfaces of peds or the walls of voids have been coated with "clay" by deposition after illuviation in suspension. These phenomena are usually recognized in reflected light with magnifications up to 60x.

Brewer (7) thinks that the terms "clay skins" and "tonhäütchen" are inappropriate and proposed to coin a new term, "cutan"¹ (plural form, cutans; adjectival form,

¹The term, cutan, is derived from the Latin, cutis, "a coating, ring, or surface of a thing" (Gell and Haigh, 1928); the ending has been changed for convenience in usage and so that the term can be defined without fear of confusion due to attempted translations of the original Latin.
cutanic), to include all the variations in the phenomena of coatings on the walls of voids, channels and ped surface. Thus, a cutan is defined as a modification of the texture, structure, or fabric at natural surfaces in soil materials due to the concentration of particular components or in situ modification of the soil; cutans can be composed of any of the component substances of the soil.

In recent years, Soileau, Jackson, and McCracken (42) found that plant growth and potassium uptake were restricted in the presence of iron-Kaolinite coatings on K-rich illite aggregates compared with plants grown in aggregates without coatings. Moreover, they found that the presence of coatings resulted in an appreciable increase in Ca and Mg accumulation by the plants. The method they used for the formation of clay coatings was similar to that used by Jenny and Smith (22).
PURPOSE OF INVESTIGATION

It is evident from a review of the literature that little information has been presented which can be used to substantiate the effect of clay deposition in soil on plant growth and nutrient uptake. Sometimes, clay deposition takes place too deep in the profile for the plant roots to reach. On the other hand, clay deposition takes place somewhere in the zone explored by plant roots. This zone may be called the solum (plural, sola) and can be defined as the upper, most weathered part of the soil profile, including the A and B horizons (48). A precise definition of the solum would be the "genetic soil" which was developed by factors and processes of soil formation. However, the solum may not always be the only zone explored by plant roots. It depends on the plant itself, the environment and the physical and chemical properties of the solum. Generally, it can be said that most grasses are restricted to the solum while trees may have their roots beyond this zone. Nevertheless, the bulk of all plant roots are to be found in the solum because of its high fertility and good environmental conditions for plant growth. From an agricultural standpoint, the accumulation or deposition of clays in the solum is of greatest importance as to its effect upon plant growth and nutrient
uptake. Furthermore, in more humid and irrigated lands this process of clay deposition would certainly be a major factor in the areas of drainage, root penetration, and nutrient uptake.

Undoubtedly, in heavy soils under successive irrigations, year after year, this deposition layer of clay might become so significant that the yield of agricultural plants would change. In sandy soils, this process of clay deposition might be beneficial as to the increase of water holding capacity, the cation exchange capacity, etc. The research reported deals only with heavy soils regarding deposition of clays in the soil and its effects on plant growth and nutrient uptake. The problem of clay deposition is of sufficient interest and importance to warrant detailed study.
EXPERIMENTAL METHODS AND PROCEDURES

The following sections are intended to provide a detailed description of the various procedures and steps which were used in this project.

Characteristics of the Experimental Soil

The soil material used throughout this study was from a profile classified as a White House sandy loam. This soil is classified as Normargidic Argiustolls, members of a fine mixed, mesic family. Characteristically, these soils have dark colored A and upper B horizons with one per cent or more organic matter, are slightly to strongly acid in the surface (pH 5.5 to 6.5), and have an A, B, Bca, C, or Cca horizon sequence. Smith (40) has reported results of the mechanical analysis and carbonates of all horizons of this soil. Table I shows these results.

In the solum of the White House profile, the clay mineralogy is predominantly illite with appreciable quantities of kaolinite and no montmorillonite whereas in the C Horizon the clay mineralogy is predominantly montmorillonite with limited amounts of illite and very limited amounts of kaolinite (40). These soils are well drained and the permeability of the profile is moderately slow to slow. The description of the soil profile of the White
Table I. Some physical characteristics of the White House profile (40).

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<th>Depth in.</th>
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<th>Silt %</th>
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<td>55.32</td>
<td>28.37</td>
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<tr>
<td>6-10</td>
<td>B1</td>
<td>41.89</td>
<td>23.62</td>
<td>34.49</td>
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</tbody>
</table>
House series is taken from the National Cooperative Soil Survey U.S.A. (50) (Appendix I).

**Description of Sampling Site**

The sampling site of the White House sandy loam profile is located three miles south and 4.5 miles east of Sonoita, Santa Cruz County, Arizona. The topography of the area is gently sloping with a slope of 2 to 3 per cent. The surface runoff is medium. These soils are used primarily as range. Some areas are cultivated and irrigated. Native grasses are mainly sprucetop, hairy, sideoats and blue grama. Brush is calliandra, mesquite and Apache plume. The elevation is about 4,950 feet. The water table is deep.

The climate of Southern Arizona between elevation of 4,000 and 6,000 feet is semi-arid. The average annual precipitation ranges from 12 to 20 inches, and occurs during two distinct seasons, summer and winter. The summer rains occur primarily during July and August, and the winter rains from December through February. The potential evapotranspiration for the region is about 30 inches (41). The mean annual temperature varies from 55° to 60° F.

**Sampling for Experimental Study**

Samples were taken from B22t horizon at a depth between 16 and 24 inches. This particular horizon has a clay content of 53.17 per cent. Thin discontinuous clay skins and pressure cutans were observed in thin sections.
(50). The clay in the B horizon is believed to be the result of both illuviation and formation in situ (40).

Sample Preparation

The soil material at air dry was treated as follows:

1. One part was ground in order to destroy clay deposition on peds and to be used as a control. The peds were crushed with a heavy hammer and were not screened.

2. The other part did not receive this treatment, but was used as taken from the field. It included peds, gravel, and crushed material caused during the process of sampling.

Experimental Procedures

Plastic pots, measuring 15 centimeters in diameter and 11.5 centimeters in height, were prepared in a manner so that excess water could be removed by suction. As many as twelve pots were used. In the bottom of all pots a layer of 1/2 centimeter of sand was placed to permit good drainage and to avoid clogging the tube used for suction. Then, all twelve pots were filled with soil material in the following order:

1. Four pots were filled with the ground soil material and thus were used as the control.
2. Four pots were filled with the unground soil material and later were leached with a suspension of kaolinite and Moroccan soil.

3. Four pots were filled with the unground soil material and later were leached with a Moroccan soil suspension.

Before proceeding with the leachings all twelve pots were subject to watering to provide stability of soil material in the pots. Although no effort was made to put the same weight of soil in each pot, this procedure helped to bring about the same level in all pots. Finally, all pots were ready for their specific treatments.

**Treatment Procedure**

The control and the kaolinite treatment received leaching at the same time and the same volume. The control received 200 milliliters of water while the kaolinite treatment received 200 milliliters of a 2 per cent clay suspension at each leaching. After allowing the suspension or distilled water to wet the soil material of the pots, a partial suction by a water aspirator was applied. A filtering flask was used to collect the clay suspension from each pot and was reused in the next leaching. Figure 1 shows a schematic drawing of the leaching apparatus. Then the pots were allowed to stand until drying was noticed before receiving the next leaching.
Fig. 1. Schematic Drawing of the Leaching Apparatus
After six leachings, or six wettings and drying, the soil from one pot of each treatment was removed to make thin sections. There was no evidence of clay skin formation. However, there was a coating of kaolinite clay around the peds. Figure 4 illustrates the deposition of kaolinite clay on soil structures.

The third soil treatment started by infiltrating with kaolinite suspensions followed by Moroccan soil suspensions. The same infiltration procedure was used as before. Originally, it was hoped to form clay skins in this study and for that reason this series of treatments was made. Twelve wetting and drying cycles of the control and kaolinite treatment were made. The control received twelve leachings of distilled water, the kaolinite treatment also received twelve leachings (6 of kaolinite and 6 of the Moroccan soil) and the last treatment received only six leachings. A final thin section was made in the laboratory. The results show that there was no evidence of clay skin formations. However, the presence of clay deposition was observed and an illustration of this phenomenon is reported.

Thin Section

Procedure

Figure 2 shows a schematic drawing of the apparatus used for impregnation. A vacuum pump capable of producing
Fig. 2. Schematic Drawing of the Apparatus Used for Impregnation
a vacuum of 7 millimeters of Hg was used. A bell jar with two openings, one on the top and the other on the side, a mercury manometer, two stopcork valves, vacuum hose and glass tubing for connecting the pump to the bell jar and manometer were used. A dehydrating tube was placed at the intake of the pump. The soil sample was oven dried at 105° to 110° C. for about 24 hours. The impregnating mixture was made of 55 per cent laminic resin and 45 per cent styrene mixture, with about 20 to 25 drops Castelite hardener per 300 milliliters. The dried sample was then placed in the container under the bell jar. The pressure was maintained for about one minute. The impregnating material was allowed to flow slowly into the sample container. The pump was turned off to reduce boiling. The sample was completely covered by sufficient liquid to keep it flooded after the vacuum was released. Then, the sample was taken out of the jar and allowed to reach a temperature of about 70° C. for a period of 8 hours prior to placing it in the oven. The sample was placed in an oven at 100° C. for 12 hours, to harden. After cooling, the paper container was torn off and discarded; the sample was cut with a diamond saw, ground and mounted by conventional thin section technique.
Characteristics of Clays Used

Kaolinite Clay

The kaolinite clay was obtained from Georgia Kaolin Company (51), referred to as Hydrite Kaolinites that are selectively mined, hydrated aluminum silicates manufactured to carefully controlled particle-size distributions. They have a high degree of purity and are processed to conform to specifications determined by their end use. They are classified into many grades. The one used in this project was Hydrite 121.

Moroccan Soil

Upon his return to Morocco for a summer visit, the author brought with him a sample of soil with high content of clay for the purpose of identification and study. This type of soil is used by natives of the area to cover the roofs of the houses against rainfall and snow. In other words, it is used as a protective means instead of tile.

The sampling site is located in Malek's farm at Ahermoumou in the lower ridges of the Middle Atlas. This soil is found at various places in deposition going from a depth of 20 to 40 meters. This particular sample was taken from a depth of 1 meter. Mechanical analysis and clay identification were determined for this particular soil.
The method of Bouyoucos was used for soil separates content and it was found that this soil contained 59.28 per cent clay, 24 per cent silt, and 16.72 per cent sand.

The method of Kittrick and Hope (24) was used for the particle-size separation for X-ray diffraction analysis. The 2 micron size fraction was used for the purpose of clay identification. Oriented glass slides were used as the method of determination.

Schedule of Operations

The sample was run as follows:

1. **Air dry**: To find out in general what was present.

2. **Expose to Ethylene Glycol**: To see if there was any basal plane expansion. (To determine montmorillonite.)

3. **Heat at 350°C. overnight**: To see if there is any change in basal plane spacing. If kaolinite is present the 7.2 Å peak should remain after heating. If the 14.0 Å basal plane peak shifts upon heating the second order (7.0 Å) and the third order (3.5 Å) peaks should also shift. If they do shift then vermiculite rather than chlorite may be suspected.

4. **Heat at 500°C. overnight**: Kaolinite will be destroyed. (7.2 Å peak will disappear.) If a 7.0 Å peak remains then it is a second order peak of chlorite. If the 14.0 Å peak moves to about
12.0 Å and all orders move proportionally, then vermiculite is present.

5. Heat at 600° C. overnight: To establish that only chlorite (14.0 Å) is present.

As a result of these treatments, it can be seen from Figure 3, that after ethylene glycol treatment the same pattern was obtained as in the dry air treatment. That is to say that the sample does not contain any montmorillonite clay. At 350° C. the 7 Å peak still remains and it means that kaolinite is present in the sample. Also, the 14 Å peak remains and did not shift. It explains that chlorite is expected rather than vermiculite. At 500° C. the 7 Å peak is almost destroyed and the 14 Å peak still remains. From all these data, it can be said that chlorite clay and kaolinite clay with a trace of talc are the dominant type of clay in this particular Moroccan soil. The 600° C. treatment was not possible at the time of identification because of the oriented glass slide method (melting point of glass).

Green House Experiment

Once all pots received their specific treatments they were placed in the greenhouse for plant growth purposes. A layer of 1/2 centimeter of sand was put over the soil material in each pot to give the same environment for seed germination and also to reduce evaporation.
Fig. 3. X-Ray Diffraction Analysis for Moroccan Soil
Ten wheat seeds, variety Ramona 50, were planted in each pot within the layer of sand. After germination, they were thinned to seven plants per pot because of germination failure in some pots. The pots were watered every 10 days with a water hose. No effort was made to determine the amount of water needed as well as the time of need.

The plants were grown for seven weeks. The above-ground portions of the plants were harvested by cutting just above the soil material level. The pots were dismounted with great care to obtain roots. The plants and roots were dried in the oven at 60° C. for 36 hours. The dry weights were used as measure of the yield. The top dry plant material was ground to pass a 40-mesh screen and stored for the analytical determination of N, P, and K.

Chemical Analyses

Total nitrogen, phosphorus, and potassium were determined in the plant top samples.

Total Plant Nitrogen

Nitrogen analysis was accomplished by method of Bremner (9) as modified in this laboratory. This method of Bremner was converted to a micro analysis method by using smaller amounts of reagents and sample. Also, Hg O was used as a catalyst, and the digestion was allowed to proceed for three hours. An Aminco micro-Kjedahl distillation assembly (Am. Inst. Co., Silver Spring, Maryland)
was used for the ammonia distillation. Approximately 20 mg samples were taken.

Total Plant Phosphorus

The total phosphorus in the wheat plant material was determined by the Vanadate-Molybdate-Yellow-Method using the wet ashing method as described by Chapman and Pratt (20). However, slight modification in the weight of samples was made (about 1/2 gm per sample while the method suggests 2 gms).

Total Plant Potassium

The acid-mixture solution of the wet ashed method obtained for the phosphorus determination was used for potassium-determination by the use of the Beckman Flame Photometer. Calibration curve was made by using 50ppm of potassium chloride (KCl). The manual operation and adjustment of the flame photometer was followed as outlined in the instruction manual provided by the Beckman Instruments (4).

The concentrations of total nitrogen, phosphorus, and potassium of the wheat plant material, which were determined on an oven dried basis, are listed in Table III and discussed in the results section.
RESULTS AND DISCUSSION

Clay Deposition

Clay deposition was accomplished by successive leachings of the original soil material with a two per cent suspension of either kaolinite clay or a dispersed Moroccan soil material. The exact amount of deposition for each treatment is not known because the leachate for each leaching was not measured. The leachate was saved until the time of the next leaching; then enough two per cent suspension was added to the leachate to make a total amount of 200 milliliters, which was used for the next leaching. Although the quantity of leachate was small for each leaching, because most of the added suspension remained in the soil, the exact amount of material deposited cannot be calculated. However, for six leachings with the kaolinite clay the maximum amount that could have been deposited was 24 grams. The total amount of soil in each container was of the order of 2000 grams. The total amount of deposited material could not have been greater than 1.2 per cent by weight with six leachings and 2.4 per cent with twelve leachings.

A large percentage of the deposited material would reasonably be deposited on or near the soil surface. However, clay material was present in the leachate and in
the sand beneath the soil. A photomicrograph of a thin section of the sand after twelve leachings is shown in Figure 4. The reddish colored material shown in the Figure is the clay material which had been deposited there. In further explanation of the photomicrograph the large white and tan areas are sand grains, while the dark colored areas are pore spaces between mineral particles.

It is reasonable to assume that some deposition occurred throughout the soil mass even though a high percentage was deposited on or near the surface. The assumption is confirmed by the photographs in Figure 5. The two soil peds were removed from the soil material which had had six successive leachings with kaolinite suspension. The white material on the surfaces of the peds is deposited kaolinite.

Photomicrographs of thin sections of peds such as the ones shown in Figure 5 did not exhibit clay skin formation. This is the reason why additional leachings were made with the Moroccan soil. A preliminary experiment had indicated the formation of clay skins when a suspension of the Moroccan soil was added to a soil.

After the prescribed number of additions of suspension had been made and the wheat plants grown and harvested, thin sections of the soil were prepared from each treatment. Even though a thin section is a very small section of a mass of soil, differences between soils can
Fig. 4. Cross-sectional Photomicrograph of Sand Used in the Bottom of Pots (Georgia Kaolinite + Moroccan Soil Suspension) 40X, crossed nicols.
Fig. 5. Photographs showing Deposition of Georgia Kaolinite Clay on the Surface of Peds.
often be distinguished by comparing representative thin sections.

Photomicrographs which were considered representative of the soils after various treatments are shown in Figures 6, 7, and 8.

Figure 6 shows a thin section of the soil to which only water had been added (the control treatment). The presence of clay is evident by the reddish color. An interesting feature of this photomicrograph is the structure is loose and non-compact. Numerous small and large pores are very noticeable compared to any of the other cross-sectional photomicrographs. Figure 7 represents a cross-sectional photomicrograph of a ped after six leachings of kaolinite and then six leachings with the Moroccan soil. In this particular photomicrograph the brightness and white color may be due to Georgia kaolinite deposition as illustrated in Figure 5. The structure of the ped is rather compact and massive compared to Figure 6 representing the control pots. Also, fewer pores are observed because they are clogged by clay deposition. In the photomicrograph, clay is represented by the reddish color, pores by the empty black spots and mineral particles particularly quartz by the white spots embedded in clay.

Figure 8 is a cross-sectional photomicrograph of a ped after six leachings with Moroccan soil. Its structure is somewhat similar to that shown in Figure 7
Fig. 6. Cross-sectional Photomicrograph of a Ped Non-treated (control), 40X, crossed Nicols.
Fig. 7. Cross-sectional Photomicrograph of a Ped After Deposition of Moroccan Soil Suspension, 40X, Crossed Nicols.
Fig. 8. Cross-sectional Photomicrograph of a Ped After Deposition of Georgia Kaolinite + Moroccan Soil Suspension, 40X, Crossed Nicols.
except that it has larger pores as indicated by the blackness. The white spots are mainly quartz grains.

**Water Infiltration**

Upon each irrigation of all pots the water infiltration in the control pots was rather high compared to those that received clay suspension. It was observed that water infiltrated in the control pots within 10 to 20 minutes while water remained in those treated for at least 3 to 5 hours and at times 12 hours. As a matter of fact, this poor infiltration brought about an irregularity in irrigation time. The control pots needed water at an earlier time than the treated pots. For this reason, the control pots were irrigated twice a week while the treated pots received only one irrigation per week. The poor infiltration and percolation in the treated pots might have been the cause of poor root growth.

**Observation of Top Growth, Root Growth, Measurements, and Nutrient Analysis**

After germination of seeds, plants were thinned to seven plants per pot. After 10 days of growth, the treated pots showed yellowish green leaves with older leaves drying up. In the control pots this symptom was not evident at this time. Slight differences in top growth between plants of the control pots and the treated pots were first observed after 20 days, the control pots exhibiting more growth. By the 25th day, the control pots
developed yellowish green of some leaves, with some older leaves drying up, but it was not as pronounced as in the wheat grown in the pots treated. At the time of final harvest (7 weeks after planting), none of the plants had any tillers; however, the wheat plants of the control pots were somewhat taller than those of the treated pots.

Figure 9 illustrates the effect of clay deposition on plant growth. Plant I in Figure 9 represents the plant top and root system grown in treated pots and plant II grown in control pots. This particular Figure is taken from a pot of Georgia kaolinite plus Moroccan soil treatment. The most striking thing about this Figure is the root system which is greatly reduced by the clay deposition. Where clay deposition occurred, plant roots measured approximately 7 centimeters in length and were fewer compared to the control where the roots were very numerous and measured about 15 centimeters in length. As to the plant top, it can be seen that plants in the control are somewhat taller than those of the treatments.

Table II reports the dry weight of plant tops and roots. It is to be noticed that in this table the dry weights of plant tops of the treated pots are approximately the same and slightly superior to the control. This decrease in dry weight of the control is not known. The dry weight of plant roots shows the same trend except it is much more superior in the control pots than that of the
Fig. 9. Effect of Clay Deposition on Root Growth.

I: Refers to treated pots (Georgia Kaolinite + Moroccan Soil).

II: Refers to control pots.
Table II. Dry weight of plant top and roots.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Pot Number</th>
<th>Plant top gm</th>
<th>Plant Roots gm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moroccan Soil</td>
<td>1</td>
<td>1.00</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.00</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.90</td>
<td>0.50</td>
</tr>
<tr>
<td>Georgia kaolinite + Moroccan Soil</td>
<td>5</td>
<td>1.05</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1.00</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1.00</td>
<td>0.55</td>
</tr>
<tr>
<td>Control</td>
<td>C1</td>
<td>0.95</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0.85</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>0.90</td>
<td>0.70</td>
</tr>
</tbody>
</table>
treated pots. This may indicate that in treated pots, clay deposition limited oxygen through excess of water occupying the voids or through decreased rate of carbon dioxide and oxygen exchange with the atmosphere above the soil. From the preceding discussion, it has been found that pores were fewer where clay deposition occurred and this by itself would affect the physiological functioning of the roots.

**Nitrogen, Phosphorus, and Potassium**

Nitrogen, Phosphorus, and Potassium content in wheat tops were determined on wheat grown for 7 weeks. Total nitrogen, total phosphorus, and the total potassium in plants are shown in Table III. Statistical analysis showed that for phosphorus and potassium, the difference between the control pots and the treated pots was not significant. For nitrogen it was found that between Georgia kaolinite plus Moroccan soil and Moroccan soil treatments, the differences were insignificant. However, the difference in the nitrogen content of the control pots was comparatively much more significant than the other treatments.
Table III. Total nitrogen, phosphorus, and potassium content in plant top.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Pot Number</th>
<th>Nitrogen ppm</th>
<th>Phosphorus ppm</th>
<th>Potassium ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moroccan Soil</td>
<td>1</td>
<td>3980</td>
<td>519.0</td>
<td>36,344</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6020</td>
<td>522.5</td>
<td>25,090</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9290</td>
<td>409.5</td>
<td>29,112</td>
</tr>
<tr>
<td>Georgia kaolinite + Moroccan Soil</td>
<td>5</td>
<td>2250</td>
<td>211.0</td>
<td>26,376</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1410</td>
<td>206.0</td>
<td>25,098</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3090</td>
<td>507.0</td>
<td>23,729</td>
</tr>
<tr>
<td>Control</td>
<td>C1</td>
<td>20,650</td>
<td>624.0</td>
<td>30,731</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>30,017</td>
<td>449.0</td>
<td>23,140</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>36,050</td>
<td>397.0</td>
<td>29,080</td>
</tr>
</tbody>
</table>
GENERAL DISCUSSION

It must be known that movement and deposition of clays take place in all soils at various degrees and various depths depending on many factors such as rainfall, clay content of the soil, cultivation intensity, irrigation, and finally, man himself. Most people are not aware of this process because it takes place within the soil profile itself. Signs of clay deposition are not visible to everyone except to soil scientists and soil morphologists. A similar analogy would be soil erosion. Actually, clay movement and deposition constitute also a type of erosion which may be called vertical erosion. As it is known, signs of soil erosion are visible to everyone, but recognition of the present and future implications is less simple. To learn what is happening to the agricultural land it is necessary to look critically at clay deposition as a type of erosion. As stated earlier, minerals do not only form and modify in the soil but they are also being decomposed, moved and deposited (1). The chemical compositions of the moving substances may be mineral, organic, or organo-minerals. From the results it can be said that clay deposition in soil affects the physical and chemical properties of the soil which, in turn, upsets plant growth and nutrient uptake. However, where there is a great deal
of clay deposition the physical properties do mask chemical properties. Clay deposition does affect soil structure, soil porosity, soil permeability, infiltration rate, bulk density, drainage, microbial activity and many other properties. Gorbunov (19) stated that clay eluviation and illuviation may affect the characteristics of the soil such as color, texture, structure, and chemical composition. Taylor and Herbert (45) stated that three of the most frequently published explanations for poor root growth in compacted zones are the following: (1) inadequate aeration, (2) soil pores are too small for root cap to enter, and (3) some initial soil bulk density. Many research workers have reported that a decrease in root penetration was associated with an increase in soil bulk density. Since the physical conditions of a soil limit its productivity, an effort to increase the yield of crops grown on that soil by adding nutrient elements very often fails.

Baver (2) states that soil structure is the key to soil fertility. According to McGeorge (29), soil productivity studies on the irrigated lands of Arizona demand that considerable stress be placed on physical problems. In fact, in many cases structural characteristics are the principal growth-limiting factors. Baver (3) summarizes the effect of physical properties of soil on the efficient use of fertilizers in at least three ways, as follows: (1) restricting root development, (2)
impairing normal absorption of established roots, and (3) impeding microbiological activity.

The growth of sugar beets and corn is limited by aggregation and porosity. Fertilizer responses are small where these two properties are at a minimum. The use of commercial fertilizers must go hand in hand with the improvement of soil structure if maximum returns are expected.

When virgin lands of the grassland areas were brought under cultivation, there were initially high crop yields; however, these declined over a period of a few years. This decline was associated with a decline in pore space, organic matter, base saturation of the exchange complex, and an increase in bulk density. It was found by Page and Willard (31) that forty years of cropping of Nappance silty clay loam of Ohio increased the bulk density of the surface foot of soil from 66.5 to 81.7 lbs/cu. ft. The pore space decreased from 60.3 to 50.5 per cent. Clay deposition effected a definite comparable decrease in pore space.

From Figure 6, which is the control, it can be seen that there are numerous pores, capillary and non-capillary, compared to Figure 7 and 8, where most of the capillary pores have been reduced to a significant extent by clay deposition. A decrease of pore space within the soil profile under natural or artificial conditions may cause an
air-moisture relationship condition that is unfavorable for the extension of roots. If oxygen became limited through an excess of water occupying the voids or through decreased rate of carbon dioxide and oxygen exchange with the atmosphere above the soil, the physiological functioning of the roots would be impaired, the activity of beneficial microorganisms would become limited, and the growth of the plant seriously affected.

The results of this experiment quite agree with the above experiments. Figure 9 shows the effect of clay deposition on root growth. The dry weight of roots will be noted in Table II. As to nutrient element uptake. The findings of this experiment concerning nutrient element uptake indicate that total nitrogen was quite affected by clay deposition while phosphorus and potassium were not significantly affected between the control and clay deposition treatments (Table III).

The reasons for the differences in total nitrogen between the control and the clay deposition treatments are not known. However, a hypothesis may be postulated by saying that possibly the activity of beneficial microorganisms that transform nitrogen becomes limited under clay deposition.
SUMMARY

A study was made of the clay deposition in soil and its effect on plant growth and nutrient uptake. Laboratory and greenhouse experiments were conducted in a sandy loam Whitehouse soil. The soil material was collected from B horizon which is characterized by silicate clay accumulation. Addition of clay deposition was made prior to plant growth. The following conclusions may be drawn from this study: (1) the infiltration rate was decreased considerably in the pots of clay deposition, (2) a poorer root growth was obtained in the pots which received additional clay deposition, (3) clay deposition decreased the total nitrogen in plants, and (4) clay deposition did not affect the total phosphorus and potassium uptake.
# APPENDIX I

## DESCRIPTION OF THE WHITEHOUSE SANDY LOAM PROFILE

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth</th>
<th>Description (color and consistence, moist)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0-6&quot;</td>
<td>Dark brown (7.5YR 3/2) sandy loam; moderate medium to fine granular structure; friable, nonsticky, nonplastic; abundant fine roots; common fine pores; noncalcareous; slightly acid (pH 6.4); clear smooth boundary.</td>
</tr>
<tr>
<td>B1</td>
<td>6-10&quot;</td>
<td>Dark reddish-brown (5YR 3/4) clay loam; weak to moderate medium subangular blocky structure; friable, slightly sticky; slightly plastic; abundant fine roots; common fine pores; noncalcareous; neutral (pH 6.6); clear smooth boundary.</td>
</tr>
<tr>
<td>B21t</td>
<td>10-16&quot;</td>
<td>Dark reddish-brown (5YR 3/4) clay; moderate medium angular blocky structure; very firm, slightly sticky, plastic; plentiful fine roots; few fine pores; few thin clay films on ped faces; noncalcareous; neutral (pH 6.7); clear smooth boundary.</td>
</tr>
<tr>
<td>B22t</td>
<td>16-24&quot;</td>
<td>Dark reddish-brown (5YR 3/4) clay; strong medium to coarse angular blocky structure; very firm, slightly sticky, plastic; plentiful fine roots; few fine pores; common thin clay films on ped faces; noncalcareous; neutral (pH 6.9); clear smooth boundary.</td>
</tr>
<tr>
<td>B23t</td>
<td>24-29&quot;</td>
<td>Dark reddish-brown (5YR 3/4) clay; moderate to strong coarse angular blocky structure; very firm, slightly sticky, plastic; few fine roots; few fine pores; common thin clay films on ped faces; noncalcareous; neutral (pH 6.9); clear smooth boundary.</td>
</tr>
</tbody>
</table>
APPENDIX I—Continued

IIB3ca 29-40" Yellowish-red (5YR 4/6) gravelly sandy clay loam; massive; firm, nonsticky, slightly plastic; common fine pores; moderately calcareous; neutral (pH 7.3); clear smooth boundary.

IIC1 40-47" Reddish-brown (5YR 5/4) gravelly loamy sand; very friable, nonsticky, nonplastic; common medium pores; moderately calcareous; mildly alkaline (pH 7.4); gradual smooth boundary.

IIC2 47-54" Reddish-brown (5YR 5/4) gravelly loamy sand; massive; very friable, nonsticky, nonplastic; common medium pores; moderately calcareous; mildly alkaline (pH 7.5); gradual smooth boundary.

IIC3 54-60" Reddish-brown (5YR 5/4) gravelly sand; massive; very friable, nonsticky, nonplastic; common medium pores; moderately calcareous; mildly alkaline (pH 7.5); gradual smooth boundary.

IIC4 60-68" Reddish-Brown (5YR 5/4) gravelly loamy sand; massive, very friable, nonsticky, nonplastic; common medium pores; moderately calcareous; mildly alkaline (pH 7.7).
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    Class Notes. Dept. of Ag. Chem. and Soils. 
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