CHEMICAL PROPERTIES OF AN ACID PRODUCTIVE SOIL

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CHAPTER I

INTRODUCTION

Soil acidity is one of the more important properties of soils. Soil acidity occurs in regions where rainfall has been sufficient to facilitate the removal, by leaching, of exchangeable bases from the soil. Intensive crop production and use of acid forming fertilizers will encourage soil acidity.

Acid soils, soil having a pH below 7, are sometimes considered synonymous with infertile or poor soils. Both exchangeable hydrogen and Al cations are largely responsible for soil acidity. With increasing acidity, more cation exchange sites are saturated with Al and fewer nutrient element ions, such as calcium and magnesium, are available for plant use. In very acid soils the cation exchange sites can become sixty percent or more saturated with Al, at which point appreciable Al may enter the soil solution. Hydronium ions readily attack the structure of clay minerals and cause a release of trivalent Al, which may replace ions on the exchange sites. The exchangeable Al ions may hydrolyze in the soil solution and increase the acidity.

The weathering of alumino-silicate clay minerals and the presence of hydronium ions encourages the presence of Al hydroxy interlayers. The formation of hydroxy Al interlayers occur in soils under the following conditions: (1) moderately active weathering to furnish Al ions, (2) moderately acid pH of about 5.0, (3) frequent wetting and drying and (4) low organic matter content.

Intensive use of fertilizers to improve crop production can contribute to acidity. The use of acid forming fertilizers leaves an acid residue in the soil. The ammonium ions on oxidation to nitrate in effect become nitric acid.

The purpose of this study was to evaluate the relationships between soil acidity, ionized Al, and various soil and clay properties. The study involved intensively cultivated soils heavily fertilized and which showed various degrees of Al toxicity as compared to soils which had not been cultivated or fertilized.

CHAPTER II

LITERATURE REVIEW

Foy (1974), Kamprath and Foy (1971), McLean (1976), Vlamis (1953) and Ligon and Pierce (1932) believe Al toxicity represents one of the most important growth limiting factors for plants grown on acid soils. Severe Al toxicity appears to occur at a soil pH of 5.0 or below, but may occur at pH values as high as 5.5.

Troug (1916) believed that soil acidity could be divided into active and latent forms. The latent forms would be the dominant forms of soil acidity. Jackson (1963) has organized soil acidity and its neutralization into five groups according to the strength of the proton retaining sites: (1) the exchangeable hydrogen or OH_3^+, (2) exchangeable Al^{+3}, (3) positive hydroxy Al polymers containing Al-OH_2 terminal groups, (4) the weaker residual Al-OH_2 groups in hydroxy alumina, and (5) aluminosilicate dissolution reactions. Apparently, the Al ion bonds to oxygen to form widely diverse functional groups. Al is second to silicon as a coordinator in soil minerals. Al is comparable to carbon, which is the coordinating ion in soil organic matter. Jackson justifies the attachment of the Al-oxygen bond to various cations through the five group bonding arrangement in the soil mineral structures.

Pauling (1958) states that weak acids tend to share oxygens and this concept can be applied to the aluminosilicate component of the layer silicate clays. For example, a single oxygen valence site is created when a loss of one hydrogen occurs from the Al hydroxide site. The site has very weak acid strength due to the strong hydrogen bonding resulting from the electronegativity of the site. The sharing of oxygen through the aluminosilicate polymerization in the silicate layer contributes to increasing the oxygen hydroxyl ratio and therefore an increase in acid strength. Also, substitution, for example, of magnesium for Al, at the exchange site in the structure will increase the acid strength while weakening the bonding of the hydronium ion. Therefore, montmorillonite which is highly substituted would have a greater acid strength compared to the less substituted beidellite clay. Earlier work by Bradfield (1923) led to the conclusion that clay acids are weak acids.

Miller (1965) proposed the following mechanism was involved in the hydrogen to Al transformation of various clay minerals in acidic conditions. The general reaction involved in the transformation process can be stated as follows: lattice-Al + H (nonlattice) ⟶ lattice-H + Al (nonlattice). Apparently, the hydrogen ions attack the edges of the kaolinite clay, while all surfaces of the montmorillonite are attacked.

The kaolinite transformation occurs as follows. An opening or hole is created which facilitates the movement of the Al. The hydroxyl ion which is associated with the octahedral layer combines with a hydrogen ion to form water which may or may not move away from the lattice. The newly formed water could combine with Al once it has been released. This process continues to take place in the octahedral channel being controlled by diffusion and limited by the depletion of the substrate Al.

The montmorillonite transformation occurs as a homogeneous reaction between the clay and the acid. Hydrogen may react with a hydroxyl located at the crystal edge or the bottom of the hexagonal surface cavity and form water. Two additional hydrogen ions could react with the silica of Al linkages, thus freeing the Al. Therefore, each Al ion or any ion in the octahedral coordination is available for acid attack, hence the transformation proceeds uniformly over the surface as well as the edges. The concentration of Al will determine the rate of the reaction.

In acid soils, according to Jackson (1963), the monomeric alumino-hexahydronium and polyhexameric forms of Al species are the most common forms. The presence of monovalent and divalent monomers of Al should be present in insignificant amounts in acidic soils, due to their already low concentration and ease of replacement.

According the Jenny (1961), Veitch worked with NaCl extracts from acid soils which contained Al, iron, manganese, and low levels of organic matter. Veitch believed the seat of acidity to be the mineral fraction of the soil as shown by the replacement of Al by sodium.

Fisher (1969), McCart and Kamprath (1965) and Coleman et al. (1958) have shown that extractable Al is generally the predominant cation in leached soils of the southeastern United States and also the tropical regions where the soil pH is 5 or less.

Al represents the major acidic cation displaced in acid soils by neutral salts such as KCl. Amedee and Peech (1976), Coleman et al. (1958) and McLean et al. (1965) suggested that Al ions tend to dominate in countering weak-acid exchange sites in organic matter in very acid surface soils.

Russell and Russell (1950) states that acid mineral soils are Al and not hydrogen soils and that Al is freed when the soils are leached with a neutral salt solution. Harward and Coleman (1954) found that Al dominates H-Al clays when prepared by dilute acid leaching. Lin and Yu (1957) reported the presence of exchangeable Al in red and yellow soils and determined the acidity of the soils. Yarosov (1948) concluded that the exchange acidity of topsoils depends on the content of exchangeable hydrogen ion, while sorbed Al dominates the exchange acidity in the lower horizons. McLean et al. (1965) showed that high organic matter soils contain appreciable less exchangeable Al when expressed as a percent of the exchange capacity. Heddleson et al. (1960) showed that Al is more easily released by acid treatment from less weathered soils than from strongly weathered soils. Most of the acid treatments resulted in a rapid increase in the exchange acidity compared to the increase in extractable Al. The increased acidity following the acid treatment was due to the presence of both hydrogen and Al. Acid soils which have been strongly weathered contain more Al in extractable form. After leaching the strongly weathered acid soils with increments of $AlCl_3$, determinations of exchange acidity and extractable Al were made. The $AlCl_3$ leaching revealed there was an increase in acidity and extractable Al derived from that retained by the soil. The increase in the exchange acidity of the $AlCl_3$ treated soils was proportional to the increase in extractable Al. Therefore, less weathered soils can retain larger quantities of extractable Al than can strongly weathered soils. Additional work involving the behavior of Al in Al and H resins in both aqueous and alcoholic solutions indicated that acidity occurs only when hydrolysis takes place. Therefore, extractable soil Al obtained from the soil mineral complex by weathering or leaching out from the addition of an Al salt to the soil will create soil acidity.

McLean et al. (1964) believe that soil acidity appears in various forms with the following order of activity: exchangeable or permanent charge $H^+ >$ exchangeable or permanent charge $Al^{+++} >$ hydroxy-Al monomers $>$ hydroxy-Al polymers $\simeq$ organic matter acidity $\simeq$ lattice Al-OH or SiOH acidity.

Coleman et al. (1958) and Mehlich (1948) believe that exchangeable acidity can be broken down into two components for purposes of measuring by conventional methods. The components are: (1) permanent charge acidity which is identified with KCl-exchangeable Al and (2) nonexchangeable acidity with neutral salts which can be titrated in a pH range of 5.5 to 8.0. Coleman et al. (1959) suggest the sum of the calcium, magnesium, and Al cations displaced from acidic red-yellow podzolic soils by means of 1 N potassium chloride should be regarded as the permanent charge cation-exchange capacity, thus implying a relationship to the isomorphous substitution charge of the clay. Schwertmann and Jackson (1964) and Coleman and Thomas (1964) believe that isomorphous substitution charges are often neutralized by hydroxy complexes of ferric or Al ions by donating or accepting protons as the pH rises or falls. The hydrated and/or hydroxylated Al ions may be partially responsible for the apparent pH-dependent charge. Pratt (1961), Mehlich (1964), and Keeney and Corey (1963) believe in the general existence of the pH-dependent component of cation exchange capacity or acidity.

McLean et al. (1965) identify the permanent charge acidity as KCl-CEC and the nonexchangeable acidity as pH-dependent CEC when measured in KCl-leached soils with triethanolamine (TEA) at pH of 8.1. The total CEC is merely the sum of the two quantities for any condition such as low lime or high lime. Due to liming, the KCl-CEC increases, while removal of the organic matter in limed soils causes a pronounced decrease in the KCl-CEC. In high limed soils, the reduced KCl-CEC suggests the organic matter CEC sites are not available for cation exchange. The addition of lime to the soils containing organic matter, when organic matter from low limed soils was destroyed, the pH-dependent CEC was drastically reduced. Apparently, the organic matter is responsible for the pH-dependent CEC. In a given soil, the changes in KCl-CEC or in pH-dependent CEC occurs with the same magnitude whether the change was induced by liming or the destruction of the organic matter and suggests that lime neutralized the acidity by occupying the organic matter exchange sites, while the destruction of the organic matter eliminated them. The change in the pH-dependent CEC reflects the freeing of the cation exchange sites due to the displacement of complexed Al by precipitation as $Al(OH)_3$. Therefore, the addition of lime would be effective in displacing and/or precipitating Al.

Kamprath (1970) believes that a valid criterion on which to base liming rates on highly weathered leached soils can be based on the exchangeable Al. From a practical standpoint, Pearson (1975) recommends the amount of lime that should be applied to produce the desired pH should be determined by the amount of acid-forming fertilizer applied and also the kind of crop to be grown.

According to Hsu (1977), several forms of Al exist in nature and can also be prepared in the laboratory. Al forms range from crystalline Al hydroxides, oxyhydroxides to oxides. Gibbsite, an Al hydroxide polymorph, is quite common in bauxitic deposits. According to Schoen and Roberson (1970), gibbsite occurs in highly weathered acidic environments and represents the most common polymorph of Al hydroxides in nature. Al oxyhydroxides are present in bauxitic deposits, but less common in soils.

Igneous and metamorphic rocks contain high temperature products such as anhydrous Al oxides. The presence of Al compounds in soils occurs on a limited basis and can only be inherited from the parent rocks.

Crystalline Al hydroxides are composed of three polymorphs: gibbsite, bayerite, and nordstrandite. The fundamental unit of the polymorphs can be represented by two planes of close-packed OH^- ions with Al^{+3} sandwiched between them. The Al^{+3} ions occupy 66 percent of the octahedral holes and are arranged in hexagonal rings. The interior arrangement consist of each Al^{+3} sharing six OH^- with three other Al^{+3}, while each OH^- is bridged between two Al^{+3}. The edge arrangement allows each Al^{+3} to share only four OH^- with two other Al^{+3}, resulting in the other two coordination sites being occupied by one OH^- ion and one H_2O molecule which are not bridged between the Al^{+3} ions.

The overall units of the polymorphs should be conceived as a giant molecule and not discrete $Al(OH)_3$ molecules. According to Schoen and Roberson (1970), the stacking or arrangement of the units and the growth habits determine the polymorph. Megaw (1934) believed the OH^- ions in one unit are directly above the OH^- ions of another unit in gibbsite. Montoro (1942) states that in bayerite the OH^- ions in one unit exist in the depression of another closely packed unit. Bayerite has a structure similar to brucite $[Mg_3(OH)_6]$ except that all octahedral sites or holes in the brucite are occupied by magnesium ions. Van Nordstrand et al. (1956) suggest the alternation of gibbsite and bayerite arrangements exist in nordstrandite. Concerning the growth habits, gibbsite crystallizes into large hexagonal plates being well developed in the X and Y directions. Bayerite takes on the form of a pyramid, while nordstrandite appears as long rectangular prisms.

Hsu (1977) believes the chemical and structural characteristics are essentially the same for both non-crystalline and crystalline Al hydroxides. Chemical reactions in the soil are probably dominated by the non-crystalline forms due to their extremely small particle size. Non-crystalline Al hydroxide, in pure form, is not stable over time, therefore many soil components can retard or inhibit its crystallization. Continuous wetting and drying cycles in nature facilitates the formation of non-crystalline components which are more resistant to acid attack. Also, in an acidic environment large or small particles of Al hydroxide are always positively charged. Well crystallized gibbsite particles are positively charged.

Schoen and Roberson (1970) report on the development of gibbsite, bayerite, and nordstrandite. The role of pH is based on the assumption that pH is related to the hydrolyzing power of Al^{+3} in solution. In an acidic environment, Al is mainly the monomeric Al^{+3} or $Al(OH)^{+2}$ cationic species having strong hydrolyzing power which favors the formation of gibbsite. Al present as $Al(OH_4)^-$ in an alkaline medium encourages the formation of bayerite. Bayerite formation is favored by alkaline conditions, while acidic conditions favor gibbsite formation. Barnhisel and Rich (1965) state that intermediate pH favors a mixture of nordstrandite with bayerite or gibbsite.

Oxisols, soils which occur in humid tropical or subtropical uplands, contain major amounts of gibbsite in both the oxic horizon and as gravel size aggregates containing greater than 30% gibbsite. Rich et al. (1959) suggest gibbsite is a minor component in Ultisols, which occur in humid tropical, subtropical, and temperate regions. Wada and Aomine (1966) found gibbsite to be a major mineral in the Andosols of Japan.

Harrison (1934), Abbott (1958), Young and Stephen (1965) and Sherman et al. (1967) believe that gibbsite is the result of direct weathering of primary Al silicates under conditions of high rainfall, tropical of subtropical temperatures and basic or intermediate rocks. Gordon et al. (1958) and Keller (1964) suggest that under favorable weathering conditions primary Al silicates will change to Al hydroxides. Mead (1915), Harrison (1934), Allen (1952) and Bates (1962) believe that clay minerals form as intermediates in the formation of gibbsite from primary Al silicates. Gibbsite dominates the highly weathered soils, while kaolinite dominates the less weathered soils. Keller (1958) believes that gibbsite and kaolinite formation is a precipitation reaction controlled by pH and the concentration of Al and Si in the solution. Garrels and Christ (1965) produced solubility diagrams for gibbsite and kaolinite which confirms Keller's concept.

Sawhney (1958) defines the formation of Al interlayers in the interlayer spaces of 2:1-2:2 type layer silicates as soil chloritization. MacEwan (1950) observed a sharp 14 A° X-ray diffraction reflection of a soil clay and after heating the reflection became diffuse and shifted toward 10 A°. MacEwan believes in the existence of some randomly distributed material between the mica layers which prevented complete collapse of the layers when water was expelled. The material in the interlayer was probably a form of iron or Al oxide because of their abundance in soils. Brown (1953) reported the first Al interlayer as a stable dioctahedral vermiculite in some Great Britain soil clays. The clay contained a KOH-HCl extractable type "blocking material" in the interlayer space. Brown (1954) stated that the blocking material was organic matter or $[Al_m(OH)_n]^{3m-n}$ ions. Grim and Johns (1954) found a similar situation in recent sediments from Rockport, Texas and suggested that brucite islands or atolls kept the layers apart on heating, but could not prevent ethylene glycol expansion. Tamura (1957), Sawhney (1958), and Klages and White (1957) reported examples of stable minerals having interlayer Al and 14 A° spacings.

According to Sawhney (1960), the occurrence of Al interlayers in soils is essentially chloritization of 2:1 expanding layer silicates. At pH of 5.0, the Al interlayers are composed of abundant hydrated polymers of $Al(OH)_2^+$ ions. The 2:1-2:2 type layer silicates in soils release Al at a satisfactory rate for the formation of Al interlayering, according to Jackson (1962). In acid soils, the chemical weathering shows preference to the formation of interlayer precipitation of $Al(OH)_3$ gel in expansible layer silicates over a precipitation of a free phase of gibbsite. Therefore, no gibbsite occurs in the interlayer spaces. The following two lines of evidence are used to support the theory that crystalline gibbsite does not precipitate within the interlayer spaces: (1) clays which are interlayers with aluminum polymers can occur in both acidic and alkaline soils, (2) sorption of Al from a solution by Al saturated montmorillonite results in lowering of the pH, thus indicating the formation and polymerization of hydroxy-Al.

Jackson (1963) believes that layer silicates act as templates for the occurrence of interlayer polymerization and weathered Al is released and deposited in 2:1 and 2:2 intergrades with aluminohexahydronium interlayers rather than gibbsite.

Schwertmann and Jackson (1963) report that montmorillonite and vermiculite are able to polymerize and hydrolyze Al in the presence of exchangeable Al. Apparently, Al ions are weathered from the terminal edges of the 2:1 clay minerals when attacked by exchangeable hydronium. The resulting hydrated Al oxide polymers act as a preservative of the clay mineral and results in a reduced cation exchange. Clay preservation can be due to: (1) replacement of other cations by the Al polymers, (2) interlayer protection of the 2:1 lattice, and (3) providing a source of Al for the lattice destructive phosphates. Clays heavily interlayered with Al hydroxide polymers were found near the surface horizons and weathered more rapidly than clays in the lower horizons. Barnhisel (1977) found more interlayering in the surface horizons and the frequency of interlayering decreasing with depth. The highest frequency of occurrence of hydroxy interlayers occurred in the Ultisol and Alfisols. Harrison and Murray (1957) believe that the weathering environment was acidic in nature and potassium was removed from the micaceous minerals, thus allowing expansion followed by interlayering of hydroxy Al.

Sawhney (1960), Jackson (1962), and Rich (1960) believe that vermiculite has the ability to bind the Al interlayers more firmly than montmorillonite in the interlayer spaces. Apparently, the cation exchange sites are highly concentrated in the expansible 14 A^o minerals, thus providing a more extensive and stable exchange site compared to the swelling intergrades. The stable exchange site is covered by positively charged Al interlayer groups and results in the formation and polymerization of hexaaluminohydroxyhydronium units.

The characteristic 14 A^o spacing of vermiculite allows the positively charged Al polymers to attach to both surfaces resulting in less interlayer building in vermiculite than montmorillonite. Apparently, isomorphoric substitution in the silica tetrahedral layer of vermiculite creates a high negative charge which is satisfied by the positively charged Al polymers. The affinity for positive and negative charges results in higher levels of interlayering in vermiculite over montmorillonite according to Jackson (1962). Jackson's concept is supported by Frink's (1965) findings concerning the abundance of interlayered Al in soils containing vermiculite clays. However, Kidder and Reed (1972) found complete interlayering in highly charged montmorillonite which is contrary to the conclusion by Frink (1965) and Jackson (1962). It would appear that montmorillonite would also develop strong interlayered clay.

Barnhisel (1977) believes the layer structures of the hydroxy interlayered vermiculite and montmorillonite depend on: (1) the basic structure of the mineral, (2) the magnitude of the interlayer filling, and (3) the chemical composition of the interlayer material.

Hsu and Rich (1960) and Jackson (1960) suggest the interlayer material in the hydroxy interlayered clays consists of six membered ring structure, $Al_6(OH)_{15}^{+3}$, which is fixed by the clay and the Al is nonexchangeable. Filling the interlayer space can occur with the small six membered ring structure or with the larger and more complex polymers of hydroxy Al suggested by Jackson (1963).

According the Barnhisel (1977), the presence of Al hydroxy interlayers can have a significant influence on both the chemical and physical properties of vermiculite and montmorillonite clay minerals. A solid-solution series is created with the "pure-end-members" comprised of montmorillonite or vermiculite at one end and chlorite at the other end with hydroxy interlayered minerals as intermediate. The chemical composition of the hydroxy interlayered minerals reflects their dynamic environment. The effectiveness of Al or hydroxy-Al in modifying the properties of clay minerals depends upon the magnitude of hydroxy-Al filling of the interlayer space. The degree of stability between the Al in the soil solution and the clays containing hydroxy-Al interlayers can be very influential in the soil chemical reactions, such as sorption of phosphate, and Al phosphate and gibbsite formation.

Rich (1960) believed the extent of chloritization or Al interlayering varies from soils derived from different parent materials. The environment of the soil has a marked influence on the formation of the interlayers. For example, Nagelschmidt et al. (1940) showed that the mineralogy of well drained soils was completely different from that of poorly drained soils located in the same area where kaolinite dominated the poorly drained soils.

The presence of hydroxy interlayers can greatly influence the following soil and clay properties: surface area, cation exchange capacity, fixation of cations, swelling and shrinkage of clays, etc.

Barnhisel (1977) believes the hydroxy interlayers could affect the cation exchange capacity by occupying the exchange sites and not allowing the saturated cation to come in contact with the exchange sites due to physical blockage. Clark (1964) found a reduction in cation exchange capacity due to the formation of interlayers. Paver and Marshall (1934) reported iron and Al retention by montmorillonite with cation exchange capacity reduction. Dixon and Jackson (1962) found interlayer material in the chlorite and vermiculite clays of the acidic red-yellow Podzolic soils. Removal of the interlayers resulted in an increase in the cation exchange capacity corresponding to the amount of interlayer material present. Sawhney (1960) showed a 30 to 40 percent increase in cation exchange capacity after the removal of the interlayer Al. The increase in cation exchange capacity appeared to be higher in the upper horizons of the soil profile. Therefore, greater interlayering and stability should occur in the upper horizons of acid soils due to the greater surface weathering and release of Al ions.

Rich (1960) reported the affect of interlayers in ion fixation in terms of restricted potassium fixation by vermiculite due to the presence of interlayer islands which prop open the silicate layers. Rich and Black (1964) suggested the interlayers affect the selectivity of ions by allowing potassium size ions to enter without hindrance from the collapsing of the partially opened mica layers.

The detailed study by Hingston et al. (1967, 1972, 1974) suggested the following types of ion sorption associated with Al hydroxides. First, nonspecific sorption of anions involves ions such as NO_3^-, ClO_4^-, and Cl^-. These ions can be sorbed by the positive charged surfaces and held loosely in the diffuse layer. Second, specific sorption of anions of completely dissociated acids, for example SO_4^{-2} and F^-, which are chemically sorbed and usually involves a ligand exchange with the surface water. Third, specific sorption of ions of incompletely dissociated acids, such as phosphate and silicate, which must have a proton donor (acid) and a proton acceptor (base) in order to occur.

Barnhisel (1969) measured the surface areas of montmorillonite and vermiculite and found a progressive reduction of surface area with the increasing presence of interlayer Al. The formation of Al interlayers reduced the internal surface by neutralizing the negative charge sites on the montmorillonite by forming islands. The space remaining around the islands could be occupied by organic molecules and would reflect the reduction in surface area. The vermiculite particles are larger and more rigid than the montmorillonite, therefore the interlayer space between the vermiculite sheets is reduced. The deposition of the hydroxy-Al polymers frequently occurs along the crystal edges of the vermiculite due to reduced interlayer space.

Clays, which have not responded to earlier treatment with organic molecules, often swell once the interlayer material has been removed according to Tamura (1957). Stephen and MacEwan (1951) believe that a bonding action by the hydroxy-cation polymer exist due to the presence of swelling chlorite. The bonding action could inhibit swelling and the amount of negative charge on the silicate layers should determine the level of bonding.

Glenn et al. (1960) and Jackson (1963) state that chlorites with OH-Al "brucite" sheets could alter to kaolinite and this may account for the absence of complete interlayer brucite sheets. Hydroxy-Al interlayer montmorillonite treated with 1N HCl at 200°C for seven days will be transformed into kaolinite according to Altschuler et al. (1963) and Poncelot and Brindley (1967). Glenn et al. (1960) suggested that soil clays undergo a transformation in which one of the two silica sheets in chloritized montmorillonite is inverted and forms kaolinite due to bond reorientation.

Spyridakis et al. (1967) proposed the following weathering sequence: biotite to hydroxy-Al interlayer vermiculite to kaolinite. Apparently, no kaolinite formed in the presence of organic matter. As the Al was released by weathering, the organic matter complexed it. Edwards and Bremner (1967) suggested the presence of organic matter in conjunction with Al could promote soil aggregation by the following linkage: clay-(Al, Fe)-organic matter-(Al,Fe)-clay.

CHAPTER III

METHODS AND MATERIALS

Location and Field Procedures

The area in Oklahoma where the field studies were made was in Garfield and Major counties. Soil samples were collected near Carrier and Lahoma Oklahoma. The Carrier location consisted of three sampling sites designated as Carrier, Healy, and Virgin. The cultivated Carrier site where Al toxicity had been observed was located 1.6 km North and 1.6 km east of Carrier, Oklahoma in Section 12, Twp. 23N, R 8 W. The cultivated Healy site which showed no signs of Al toxicity was located north of the Carrier site in Section 1, Twp. 23 N, R 8 W. The Virgin site was 2.4 km south of the Carrier site in Section 18, Twp. 23 N, R 7 W. The Lahoma location consisted of one cultivated sampling site where Al toxicity had been observed designated as Lahoma and located 6.4 km S and .4 km N of the OSU North Central Agricultural Research Station in Section 36 Twp. 21 N, R 9 W in Major county.

The Carrier, Healy, and Virgin soil samples are currently classified as Udic Argiustolls, fine silty, mixed, thermic. All the soil samples from the Carrier location belong to the Pond Creek series which consist of dark-brown, very fertile, well drained, nearly level soils having excellent capacity to take in and store moisture. The Pond Creek soils represent immature upland soils formed in calcareous loesslike materials.

The Lahoma soil samples are currently classified as Aquic Arenic

Haplustalfs, loamy, mixed, thermic. The soil samples from the Lahoma location belong to the Meno series which consist of deep loamy fine sands occurring on nearly level to gently undulating upland topography. The soils of the Meno series have been leached throughout and are medium acid. The soils were formed from old alluvium modified by wind and form thick deposits of sandy material stratified with clay loam to sand.

The Carrier and Lahoma sampling sites involved dividing the respective fields into four quadrants and sampling each quadrant in a five spot pattern. Each of the five bore holes per quadrant were samples down to ninety centimeters depth. Five samples from each bore hole represent the following intervals: 0 to 15 cms, 15 to 30 cms, 30 to 45 cms, 45 to 60 cms, and 60 to 90 cms.

Additional soil sampling occurred north of Carrier at the Healy site which involved sampling one bore hole. Also, south of Carrier at the Virgin soil site one quadrant with a five replication pattern was sampled.

All two hundred thirty soil samples were individually placed into marked paper bags for shipment to the laboratories at Oklahoma State University. The one hundred Lahoma samples were consecutively numbered from 452 to 551. The one hundred Lahoma samples were consecutively numbered from 552 to 651. The five Healy samples received the numbers 652 to 656, while the twenty-five Virgin soil samples were consecutively numbered from 700 to 724. In addition to the sample number, each bag was marked indicating sampling site, quadrant location, hole location, and depth.

Laboratory Procedures

Upon arrival at the laboratory, the soil samples were allowed to air dry for several days before being crushed by hand and ground in a motor driven mortar and pestle grinding apparatus. Before, during, and after grinding all foreign matter such as roots, stems, and rocks were removed from the ground soil samples. The ground air dried soils were passed thru a 20 mesh sieve before being placed into labelled paper cartons for storage purposes.

The particle-size analysis Bouyoucous (1926) and Day (1956) involves the use of a hydrometer in the sedimentation process. The analysis involves 50 grams of air dried soil being placed into 250 ml centrifuge bottles containing 100 to 150 ml deionized water shaken for 15 minutes and then allowed to soak for several hours. According to Jackson et al. (1950) a dilute solution of sodium carbonate ($NaCO_3$) was added as a dispersing agent. Various amounts of a 2% solution of sodium carbonate--sodium bicarbonate were added to create a pH of approximately 9.0 to facilitate dispersion. The dispersed samples were transferred to 1000 ml sedimentation cylinders and deionized water was added to bring the soil suspension to the 1000 ml mark. The dispersed soil suspensions were vigorously agitated and the hydrometer was used to determine the rate of particle settling. Two hydrometer readings were ascertained at 40 seconds and at one hour intervals. The resulting particle-size analysis data were used in obtaining the textural classification of the soils.

According to Peech et al. (1947), a soil-to-water ratio of 1:1 should be used in measuring the pH of a soil paste. Many European researchers e.g., Puri and Asghar (1938), believe the pH of the soil should be measured in a soil paste containing 1N KCl instead of water. Both methods of measuring the soil pH were used. Therefore, ten gram samples of the air dried soil were used. The ten gram soil samples and 10 ml of deionized water was mixed and allowed to stand for two hours after the initial mixing. The pH of soil-water pastes were determined on the Corning Model 10 pH meter. After the soil-water pH was ascertained, 10 ml of 1 N KCl was added and after a two hour equilibrium period, the pH was determined on the soil-salt paste.

A modification of the Schollenberger (1931) procedure for determining organic matter by the wet combustion method was used. The method involves slowly heating a potassium dichromate-sulfuric acid solution containing one-half gram of soil to 160-170°C. One hundred and twenty-five ml of cold water is added to the cooled mixture before titrating with ferrous ammonium sulfate.

Richards (1954), and Schollenberger and Simon (1945) recommended the use of ammonium acetate for determining the exchangeable cations in the soil. The determination of exchangeable cations involved the use of 20 gram samples of air dried soil being placed into 250 ml Erlenmeyer flasks with 200 ml of 1 N ammonium acetate. The soil solutions were shaken initially and allowed to stand overnight before being filtered through Whatman No. 2 filter paper. The leachates were analyzed on the Perkin Elmer Model 403 Atomic Absorption Spectrophotometer for exchangeable cations.

Coleman et al. (1959) and Pratt and Bair (1961) state that exchangeable Al can be obtained by leaching the soil with a normal solution of a neutral salt. Water soluble Al can be determined by leaching the soil with deionized water. The determination of exchangeable and water soluble Al involved the extraction of 10 gram samples of air dried soil with 100 ml of 1 N KCl or deionized water. The soil suspensions were shaken and allowed to stand overnight before being filtered through

Whatman No. 2 filter paper. The leachates were collected and analyzed on the Perkin Elmer Model 403 Atomic Absorption Spectorphotometer for water soluble of KCl extractable Al. Determinations of calcium, magnesium, sodium, and potassium were made on the water extracts.

The leaching process involves the long term application of one hundred pounds of nitrogen applied as ammonium nitrate or nitric acid to the Healy or Virgin soil samples. The laboratory procedure involved 20 grams of air dried soil leached with 50 ppm nitrogen as ammonium nitrate or nitric acid and representing an application of one hundred pounds of nitrogen per acre. The soil solutions were shaken initially and allowed to stand for several hours before being filtered. The filtration process involved filtration through Whatman No. 2 filter paper. At the conclusion of each of the twelve leachings, the soil cakes were allowed to dry for approximately one week at ambient conditions. The leachates recovered from each of the twelve leachings were analyzed for aluminum, calcium, magnesium, sodium, and potassium by atomic absorption.

Reed (1980) recommends the following methods for the determination of the cation exchange capacity of soils and clays. Ten gram samples of air dried soil are placed into 200 ml Erlenmeyer flasks with 50 ml of 1 N $CaCl_2$. The soil-salt mixtures are shaken initially and allowed to stand overnight. The mixtures are filtered through Whatman (5.5 cm) No. 2 filter paper on a Buchner funnel-vacuum flask arrangement. Three additional leachings of 50 ml of 1 N $CaCl_2$ are followed by three 50 ml washes of deionized water. The final three 50 ml 1 N $NaNO_3$ leachings are retained for calcium and chloride determinations. The calcium was analyzed by the E.D.T.A. titration and the chloride was analyzed by the

Mohr titration. According to Reed (1980), cation exchange capacity (CEC) /100 grams can be calculated as milliequivalents of calcium/100 grams minus milliequivalents of chloride/100 grams.

Jackson (1956), Kittrick and Hope (1963) and Rich and Barnhisel (1977) have developed procedures for the examination of soil clays by the X-ray diffraction technique. The separation of clay from the soil involves a 2% sodium carbonate-sodium bicarbonate pretreatment and numerous cycles of sedimentation and siphoning. The siphoned suspensions are passed through a steam turbine supercentrifuge with the fine clay particles of less than 0.2 um collected in 20 liter bottles, while the coarse clay particles larger than 0.2 um collect on the plastic sleeve inside the supercentrifuge rotor. Both the fine and coarse clay fractions are calcium saturated and dispersed by several 50 ml extractions with 1 N $CaCl_2$ and deionized water respectively. Aliquots of the calcium saturated clays are applied to porous unglazed ceramic tiles mounted in a suction device described by Rich and Barnhisel (1977). The calcium saturated clay slides are dried and X-ray diffraction recordings made before treating with 10% ethylene glycol and again diffraction data collected. Aliquots of the calcium saturated clays are treated by extracting 3 times with 1 N KCl and washing with deionized water to produce the potassium saturated clay. The ceramic slides are coated with the potassium saturated clays and allowed to dry before being X-rayed. One set of potassium saturated slides were heated for four hours at approximately 500°C for identification purposes, while additional slides were heated for two hours at approximately 100°C, 300°C, and 500°C for studying interlayer stability in the expansible clay minerals. The heated slides were cooled and X-rayed.

The calcium saturated, glycol solvated, potassium saturated, and potassium saturated heated slides were X-rayed on the General Electric XRD6 instrument with a Ni-filtered CuK radiation generated at 30 KVP and 20 ma. The General Electric XRD was operated from the lower limit of two degrees 2θ to the upper limit of thirty degrees 2θ.

Jackson (1958) recommends the aluminon method for the determination of Al in soils and clays. Before the application of the aluminon method, the clay aliquots are subjected to an extensive pretreatment. The clay aliquots were centrifuged and a known amount of clay was extracted and placed into digestion tubes containing 40 ml of 1 N sodium citrate solution. The clay-sodium citrate mixtures were heated on the Tecator Digestion System 40 1006 heating unit for thirty minutes at a sample temperature of 90°C. The heated samples were allowed to age for one hour at the elevated temperature before cooling. The samples were then centrifuged at 8,000 rpm for fifteen minutes and a total of six sodium citrate extractions were made. The initial extractions were discarded and the remaining extractions were combined for aluminum determinations. Fifty ml aliquots were removed from the extraction solutions and placed back into the digestion tubes for additional aging on the heating unit. The 50 ml aliquots were dried and the salts were subjected to the standard digestion procedures with nitric:perchloric (3:1) acid and 3 N hydrochloric acid. After the hydrochloric acid treatment, the salts were dissolved in 50 ml of deionized water and analyzed by the aluminon method. The aluminon method required one ml sample aliquots placed in a 50 ml volumetric flasks containing 10 ml each of deionized water and .4% aluminon reagent. The mixtures are diluted to the 50 ml marks with deionized water and throughly mixed before being allowed to stand for 25 minutes. The percent light transmission or absorption at 520 nanometers (nm) was determined on the Baush and Lomb Spectronic 20.

The sodium citrate treated clays were X-rayed on the General Electric XRD6 insturment and conventional methods were employed in ascertaining surface area and cation exchange capacity data.

The surface areas of layer silicates have been used as a criterion for identification. Dyal and Hendricks (1950) used ethylene glycol for determining surface area. Bower and Goertzen (1959) adapted the ethylene glycol method to determine the surface area of soils and soil minerals. Diamond and Kinter (1958) determined surface areas of clay minerals by glycerol retention. Carter et al. (1965) reported the use of ethylene glycol monoethyl ether or EGME for determining surface areas of layer silicates. The EGME method was adopted and involves activated Al drying of clay aliquots until constant weights are obtained. The constant weight clays are treated with EGME and the use of desiccator-high vacuum arrangement allows for the determination of constant weights for the EGME treated clays. According to Carter et al. (1965), surface area calculations which were adopted involves the grams of EGME retained divided by grams of vacuum dried clay multiplied by 2.86×10^{-4} grams of EGME required to form a monolayer of one square meter of surface equals the square meters per gram total surface area of the clay minerals.

CHAPTER IV

RESULTS AND DISCUSSION

Difficulty in identification was encountered with the calcium and ethylene glycol non-sodium-citrate treated clay samples due to presence of very broad, diffuse shoulders occurring from 2° to 10° 2θ and extending with only a gradual decline near 8° 2θ. A Lahoma subsoil, 15-30 cm depth, coarse clay sample, represents the typical shoulder phenomenon encountered in most samples studied (Figure 1). The calcium saturated sample produced a very broad shoulder in which shoulder surface identification produced comparable results for electronic noise and actual detection of clay minerals. The glycolated calcium saturated sample produced less "noise", but the shoulder presence probably masked the identification of clay minerals. The collapse of the mineral with potassium saturation resulted in a marked reduction of the shoulder and improved identification. The heated (500°C) potassium saturated samples showed the typical 10A peaks associated with the micaceous clay minerals.

Clay mineral identification was conducted beginning with the 500°C heated potassium treated sample and concluding with the calcium saturated sample. The presence of the shoulder could indicate excess water in the sample, presence of amorphous and/or poorly crystallized material, such as, organic matter, hydroxy aluminum polymers, iron oxides, and salts, which coat and/or occupy the surfaces of the crystalline minerals. A slight broadening of the X-ray diffraction peaks would be expected since

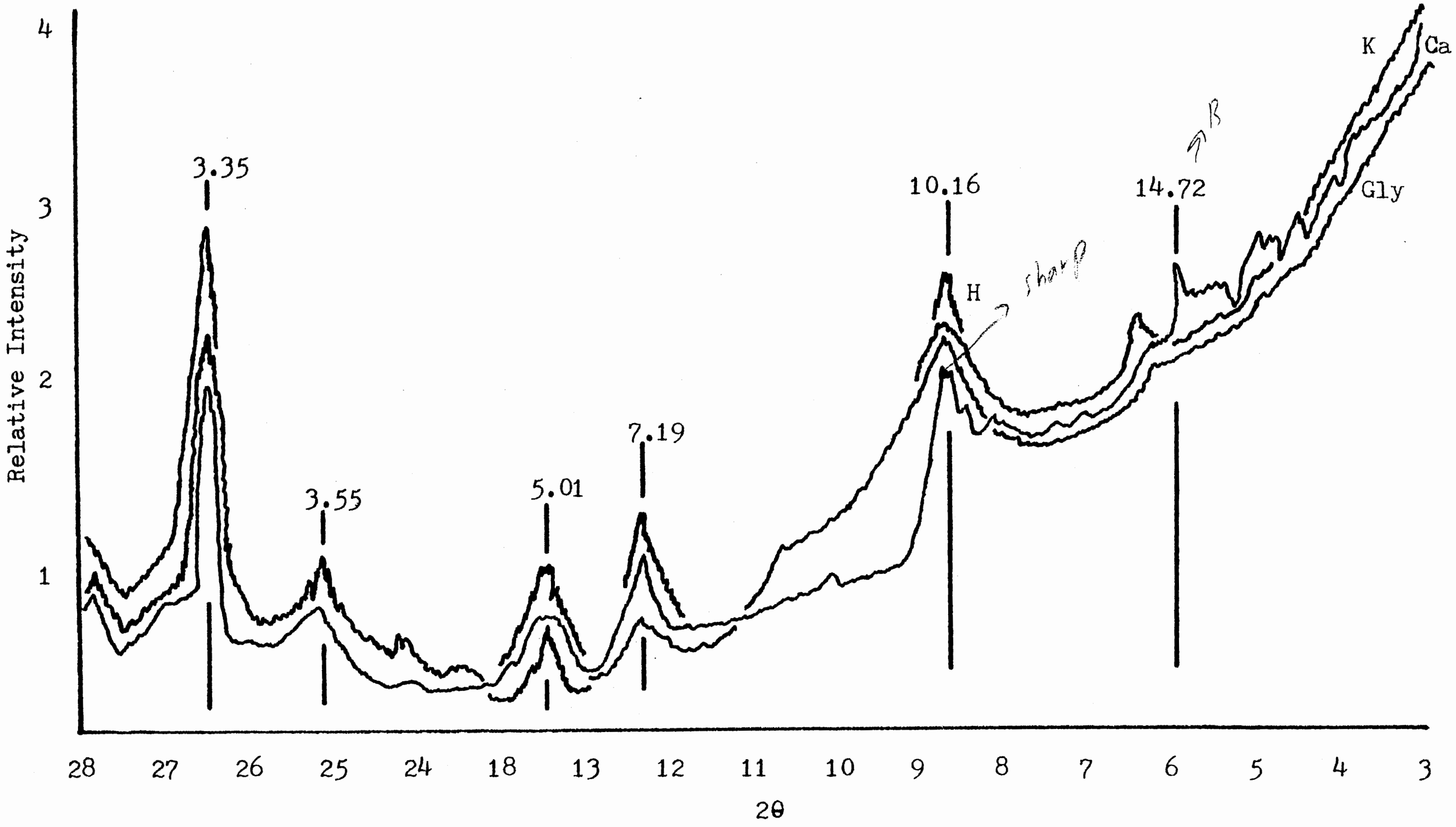

Figure 1. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 15 to 30 cm Coarse Clay Fraction

the clay fractions were studied in an "as-is" state and the customary removal of iron oxides, carbonates, soluble salts, and organic matter was not used so as to minimize damage to the interlayer material. The removal of the amorphous and/or interlayer material with sodium citrate improved the identification of the soil clay minerals by greatly reducing or eliminating the 2 to 10° 2θ shoulder. A majority of the sodium citrate treated and calcium saturated coarse and fine clay samples showed better X-ray diffraction than non-treated samples which was probably due to improved crystallinity by the reduction of or the removal of interferring material on mineral surfaces (Table I).

The X-ray diffraction patterns represent clay minerals which have developed in the soil environment studied, show minerals to be poorly crystalline when compared to the higher degree of crystallinity associated with deposit clays, which are used for reference. X-ray diffraction patterns of the Carrier, Healy, and Virgin soil clay fractions indicate a uniform clay mineralogy. Clay mineralogy of the coarse clay was dominated by hydrous mica (illite) and kaolinite, while only hydrous mica (illite) clay dominated the mineralogy of the fine fraction.

The selected X-ray diffraction patterns of the Carrier, Healy, and Virgin soils (Figures 2, 3, 4, 5, 6, 7) show excellent crystallization in the coarse fraction of clay minerals which was indicated by the 10 A° first order, 5 A° second order, and 3 A° third order spacings for hydrous mica (illite), while the Healy soil contains crystalline kaolinite as shown by the 7 A° first order and 3.5 A° second order spacings. In all cases, the more reactive fine clay fractions were shown to be more poorly crystallized with more diffuse first and especially second order spacings. With increasing soil depth and especially at the 60-90 cm depth,

TABLE I

X-RAY DIFFRACTION DATA FROM NON-TREATED AND TREATED SODIUM CITRATE CLAYS EXTRACTED FROM CARRIER, LAHOMA, HEALY AND VIRGIN SOILS (001 SPACINGS)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. 25°C	Ca sat. Gly 25°C	K sat. 25°C	K sat. 500°C	Type of Clay Mineral
Carrier	0-15	Coarse	NSC*	10.04 S	10.04 S	10.04 S	10.16 S	Illite
				7.25 S	7.25 S	7.25 S		Kaolinite
			SC*	10.27 S				Illite
				7.25 S				Kaolinite
		Fine	NSC	10.39 B	10.39 B	10.27 B	10.39 B	Illite
			SC	10.39 B				Illite
	15-30	Coarse	NSC	10.04 S	10.04 S	10.16 S	10.16 S	Illite
				7.19 S	7.19 S	7.19 S		Kaolinite
			SC	10.04 S				Illite
				7.19 S				Kaolinite
		Fine	NSC	10.39 B	10.16 B	10.39 B	10.27 B	Illite
			SC	10.52 B				Illite
	30-45	Coarse	NSC	10.04 S	10.04 S	10.04 S	10.16 S	Illite
				7.19 S	7.19 S	7.19 S		Kaolinite
			SC	10.39 S				Illite
				7.25 S				Kaolinite
		Fine	NSC	10.39 B	10.04 B	10.27 B	10.52 B	Illite
			SC	10.52 B				Illite

TABLE I (Continued)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. 25°C	Ca sat. Gly 25°C	K sat. 25°C	K sat. 500°C	Type of Clay Mineral
	45-60	Coarse	NSC	10.16 S 7.25 S	10.04 S 7.19 S ?	10.16 S 7.25 S	~~10.16 S~~	~~Illite~~ Kaolinite
			SC	10.16 S 7.25 S				Illite Kaolinite
		Fine	NSC	10.39 B	10.16 B	10.27 B	10.39 B	Illite
			SC	10.16 B				Illite
	60-90	Coarse	NSC	10.04 B 7.19 S	10.27 B 7.19 B	10.04 S 7.25 B	10.04 S	Illite Kaolinite
			SC	10.04 S 7.13 S				Illite Kaolinite
		Fine	NSC	10.52 B 7.25 B	10.27 B 7.25 B	10.27 B 7.31 B	10.27 B	Illite Kaolinite
			SC	10.39 S 7.19 B				Illite Kaolinite
Lahoma	0-15	Coarse	NSC	14.72 B 10.04 S 7.19 S	10.04 B 7.19 S ?	14.97 B 10.16 B 7.25 B	10.04 B	Vermiculite Illite Kaolinite
			SC	14.72 B 10.04 S 7.19 S				Vermiculite Illite Kaolinite
		Fine	NSC	28.48 B 10.27 W	10.04 W	14.02 W 12.10 W 10.27 B	10.27 B	Montmorillonite Vermiculite Illite Kaolinite

TABLE I (Continued)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. 25°C	Ca sat. Gly 25°C	K sat. 25°C	K sat. 500°C	Type of Clay Mineral
			SC	15.23 B				Montmorillonite
				10.27 B				Vermiculite
								Illite
	15-30	Coarse	NSC	14.72 B	10.04 S?	14.02 W	10.16 S	Vermiculite
				10.04 S	7.19 S	10.16 B		Illite
				7.19 S		7.19 S		Kaolinite
			SC	14.72 B				Vermiculite
				10.16 B				Illite
				7.19 S				Kaolinite
		Fine	NSC	25.22 B	24.52 W	12.62 B	10.27 B	Montmorillonite
				16.98 B	18.02 W	10.27 B		Vermiculite
				10.27 W	10.16 B	7.25 B		Illite
				7.25 B	7.25 B			Kaolinite
			SC	25.22 B				Montmorillonite
				15.23 B				Vermiculite
				12.99 B				Illite
				10.27 B				
	30-45	Coarse	NSC	15.23 B	10.04 B?	14.02 W	10.04 B	Montmorillonite
				10.27 B	7.19 W	12.80 W		Vermiculite
				7.13 W		10.16 B		Illite
						7.13 S		Kaolinite
			SC	14.72 B	18.02 B			Montmorillonite
				10.04 B	10.04 B			Vermiculite
				7.25 S	7.19 B			Illite
								Kaolinite

TABLE I (Continued)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. 25°C	Ca sat. Gly 25°C	K sat. 25°C	K sat. 500°C	Type of Clay Mineral
		Fine	NSC	25.22 W	25.22 W	14.24 W	10.04 B	Montmorillonite
				15.77 B	17.66 W	12.27 W		Vermiculite
				10.27 W	10.04 W	10.27 B		Illite
				7.19 W	7.25 W	7.25 W		Kaolinite
			SC	14.72 B				Montmorillonite
				10.39 B				Vermiculite
				7.25 B				Illite
								Kaolinite
	45-60	Coarse	NSC	30.44 B	10.16 B	14.48 B	12.99 W	Montmorillonite
				15.49 B	7.25 B	12.44 W	10.27 B	Vermiculite
				10.52 B		10.27 B		Illite
				7.25 S		7.13 S		Kaolinite
			SC	14.72 B	18.02			Montmorillonite
				10.04 B	10.04			Vermiculite
				7.25 B	7.19			Illite
				7.19				Kaolinite
		Fine	NSC	28.48 B	31.53 W	14.72 W	10.27 B	Montmorillonite
				16.06 B	18.79 B	12.99 W		Vermiculite
				7.19 B	7.25 B	10.27 B		Kaolinite
						7.13 B		
			SC	15.77 B				Montmorillonite
				7.19 B				Vermiculite
								Kaolinite
	60-90	Coarse	NSC	24.52 B	31.53 W	14.48 B	12.99 B	Montmorillonite
				15.49 B	19.62 B	12.10 W	10.16 S	Vermiculite
				10.04 B	10.04 B	10.27 W		Illite
				7.13 S	7.19 S	7.19 B		Kaolinite

TABLE I (Continued)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. 25°C	Ca sat. Gly 25°C	K sat. 25°C	K sat. 500°C	Type of Clay Mineral
			SC	14.72 S 10.16 B 7.13 S				Montmorillonite Vermiculite Illite Kaolinite
		Fine	NSC	29.43 W 15.77 B 10.39 W	19.19 B 10.04 W	18.39 W 15.23 W 12.99 W 10.39 W	15.23 W 10.39 B	Montmorillonite Vermiculite Chlorite Illite
			SC	14.72 B 10.27 B				Montmorillonite Vermiculite Illite
Healy	0-15	Coarse	NSC	10.04 S 7.19 S	10.04 S 7.19 S	10.16 S 7.13 S	10.04 S	Illite Kaolinite
			SC	10.04 S 7.19 S				Illite Kaolinite
		Fine	NSC	10.27 W	10.39 B	10.27 B	10.27 B	Illite
			SC	10.04 B				Illite
	15-30	Coarse	NSC	10.16 S 7.19 S	10.04 S 7.19 S	10.16 S 7.25 S	10.16 S	Illite Kaolinite
			SC	10.04 S 7.13 S				Illite Kaolinite
		Fine	NSC	10.27 W	10.04 B	10.27 B	10.16 B	Illite
			SC	10.27 B				Illite

TABLE I (Continued)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. 25°C	Ca sat. Gly 25°C	K sat. 25°C	K sat. 500°C	Type of Clay Mineral
	30-45	Coarse	NSC	10.16 S	10.04 S	10.16 S	10.04 S	Illite
				7.25 S	7.19 S	7.19 S		Kaolinite
			SC	10.04 S				Illite
				7.13 S				Kaolinite
		Fine	NSC	10.52 W	10.27 B	10.52 B	10.27 B	Illite
			SC	10.27 B				Illite
	45-60	Coarse	NSC	10.04 S	10.04 S	10.04 S	10.04 S	Illite
				7.19 S	7.19 S	7.19 S		Kaolinite
			SC	10.04 S				Illite
				7.13 S				Kaolinite
		Fine	NSC	10.52 W	10.27 B	10.27 B	10.27 B	Illite
			SC	10.27 B				Illite
	60-90	Coarse	NSC	10.04 B	10.04 S	10.04 S	10.04 S	Illite
				7.19 S	7.19 S	7.19 S		Kaolinite
			SC	10.27 S				Illite
				7.25 S				Kaolinite
		Fine	NSC	10.52 B	10.16 B	10.39 B	10.27 B	Illite
			SC	10.52 B				Illite
Virgin	0-15	Coarse	NSC	10.16 S	10.04 S	10.27 B	10.16 S	Illite
				7.19 S	7.13 S	7.19 B		Kaolinite
			SC	10.16 S				Illite
				7.19 S				Kaolinite

TABLE I (Continued)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. $25^{o}C$	Ca sat. Gly $25^{o}C$	K sat. $25^{o}C$	K sat. $500^{o}C$	Type of Clay Mineral
	15-30	Fine	NSC	10.39 W	10.16 W	10.39 W	10.39 B	Illite
			SC	10.27 B				Illite
		Coarse	NSC	10.27 S 7.25 S	10.16 S 7.25 S	10.27 S 7.25 S	10.16 S	Illite Kaolinite
			SC	10.04 S 7.19 S				Illite Kaolinite
	30-45	Fine	NSC	10.39 W	10.16 W	10.52 B	10.27 B	Illite
			SC	10.27 B				Illite
		Coarse	NSC	10.16 B 7.25 B	10.16 B 7.25 B	10.27 S 7.25 S	10.16 S	Illite Kaolinite
			SC	10.04 B 7.19 B				Illite Kaolinite
	45-60	Fine	NSC	10.39 W	10.39 B	10.39 B	10.27 B	Illite
			SC	10.27				Illite
		Coarse	NSC	10.16 S 7.25 S	10.16 S 7.25 S	10.16 S 7.19 S	10.04 S	Illite Kaolinite
			SC	10.27 S 7.19 S				Illite Kaolinite
	60-90	Fine	NSC	10.39 W	10.27 W	10.52 W	10.27 B	Illite
			SC	10.39 B				Illite
		Coarse	NSC	10.27 S 7.31 S	10.04 S 7.19 S	10.16 S 7.19 S	10.16 S	Illite Kaolinite

TABLE I (Continued)

Sample	Depth (cm)	Clay Fraction	Trt.	Ca sat. 25°C	Ca sat. Gly 25°C	K sat. 25°C	K sat. 500°C	Type of Clay Mineral
			SC	10.04 S				Illite
				7.19 S				Kaolinite
		Fine	NSC	10.52 B	10.04 S	10.52 B	10.16 B	Illite
				7.25 B	7.25 S	7.25 B		Kaolinite
			SC	10.27 W				Illite

*NSC = Non Sodium Citrate Treatment
*SC = Sodium Citrate Treatment

S = Sharp
B = Broad
W = Weak

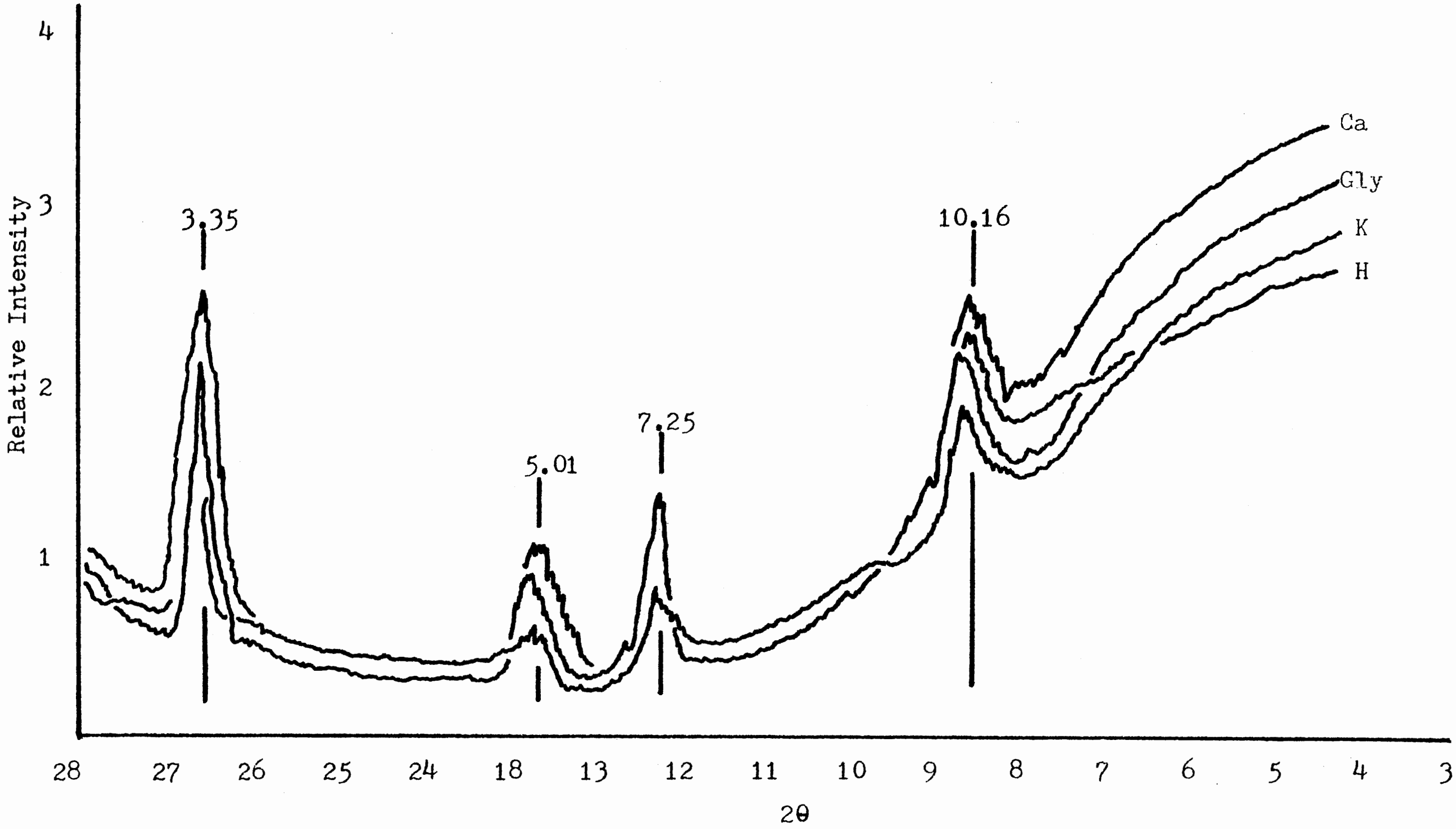

Figure 2. X-ray Diffraction Pattern and d-spacings in Angstroms of the Carrier 45 to 60 cm Coarse Clay Fraction

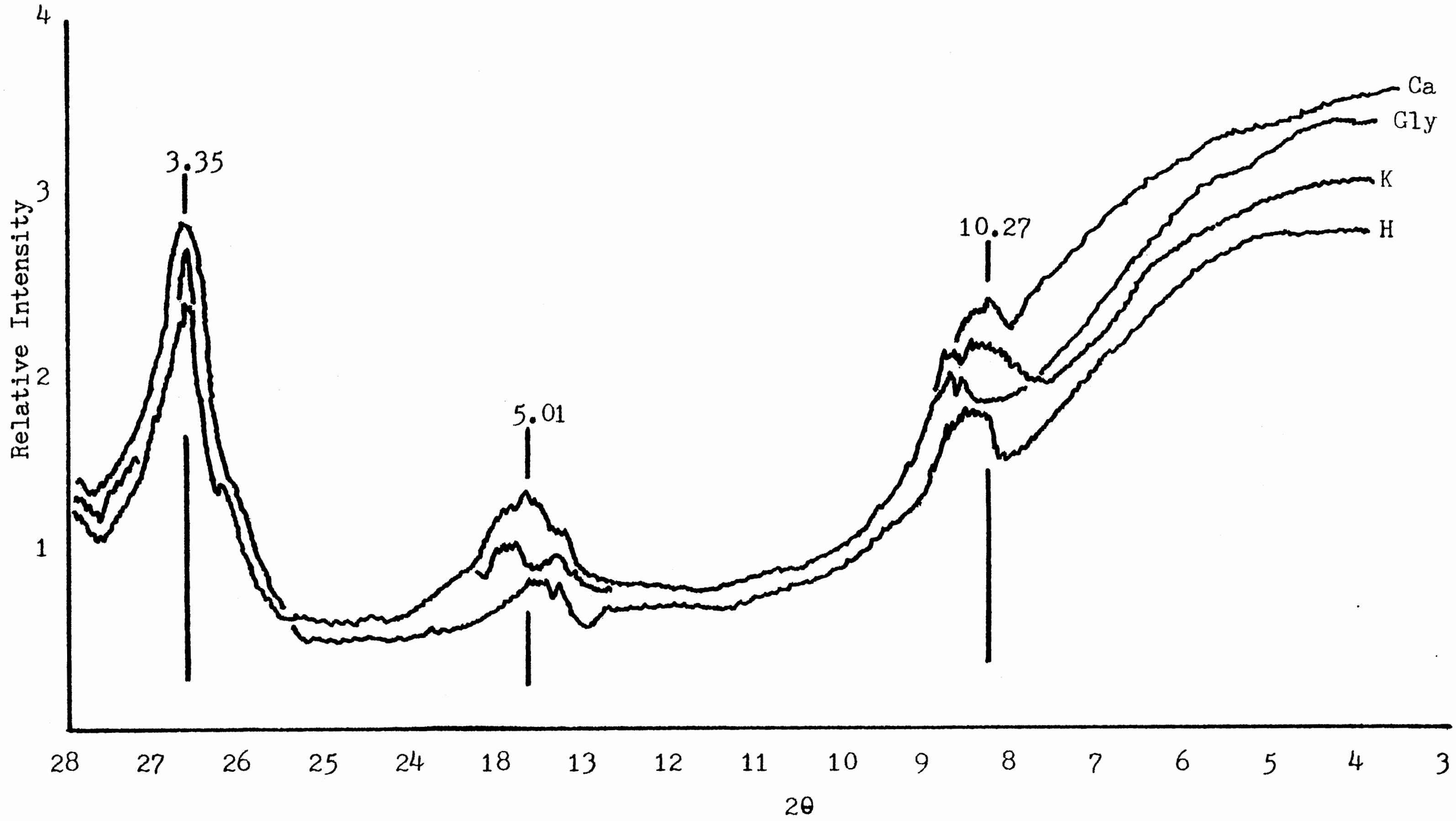

Figure 3. X-ray Diffraction Pattern and d-spacings in Angstroms of the Carrier 45 to 60 cm Fine Clay Fraction

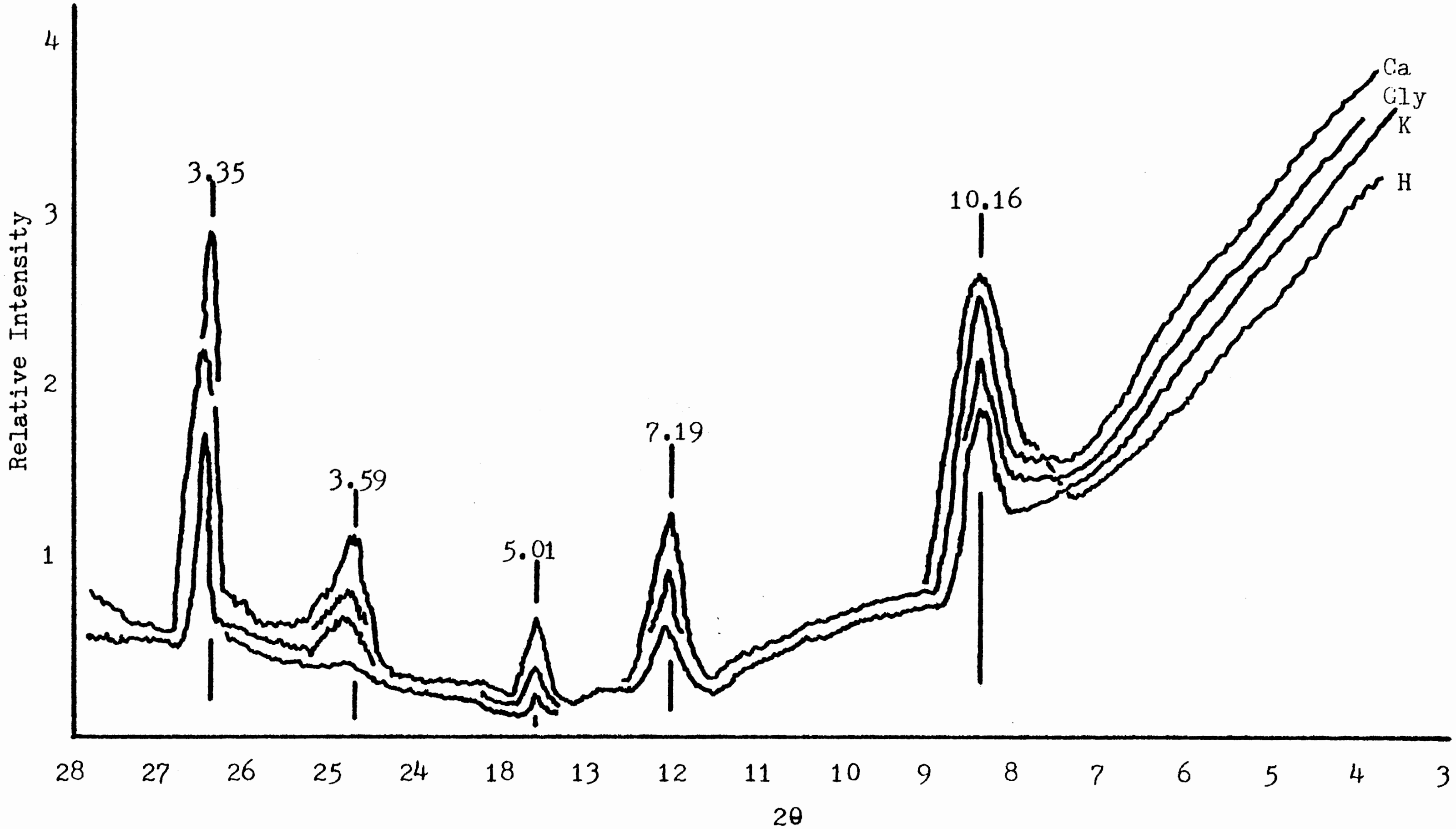

Figure 4. X-ray Diffraction Pattern and d-spacings in Angstroms of the Healy 30 to 45 cm Coarse Clay Fraction

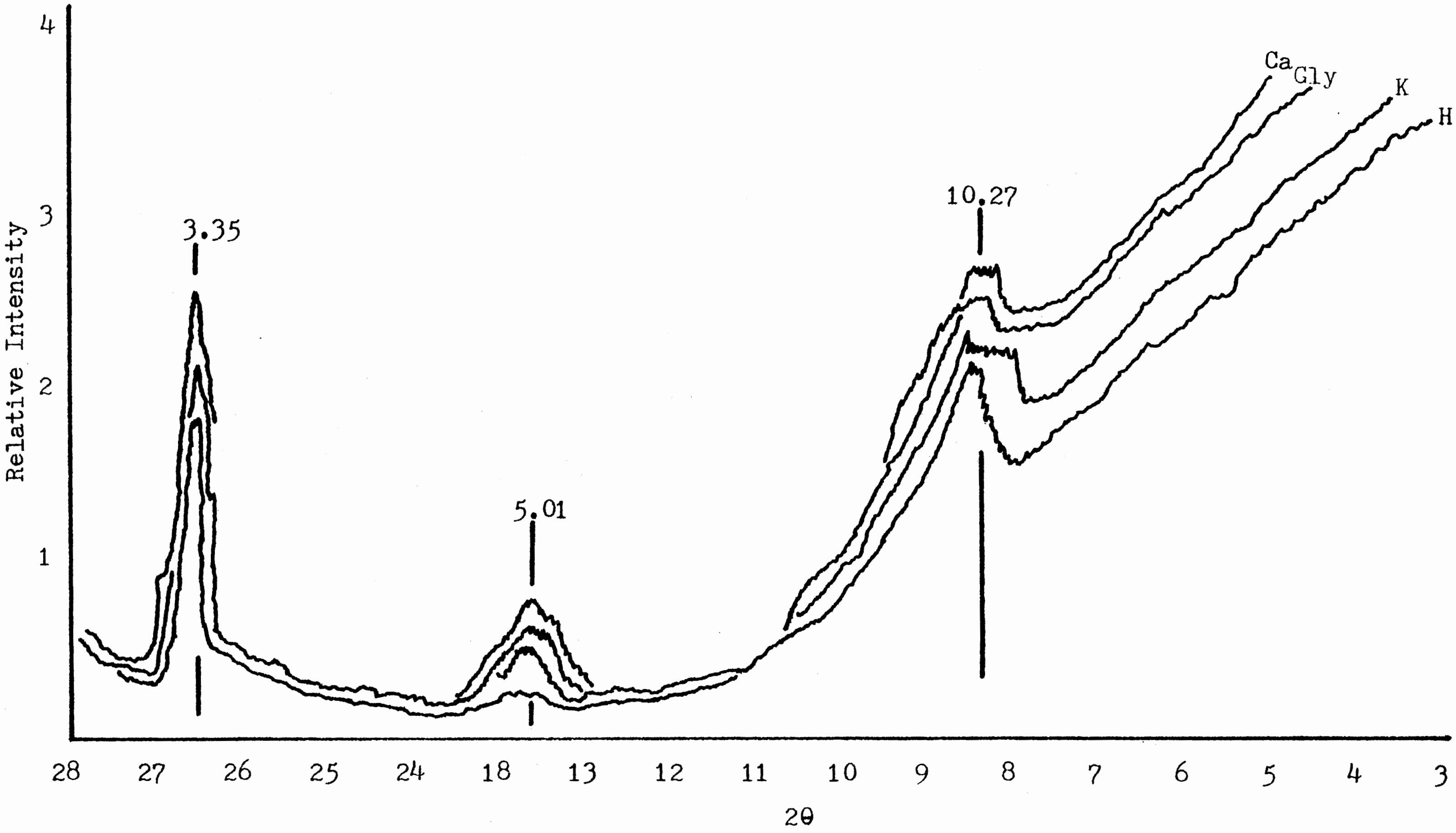

Figure 5. X-ray Diffraction Pattern and d-spacings in Angstroms of the Healy 30 to 45 cm Fine Clay Fraction

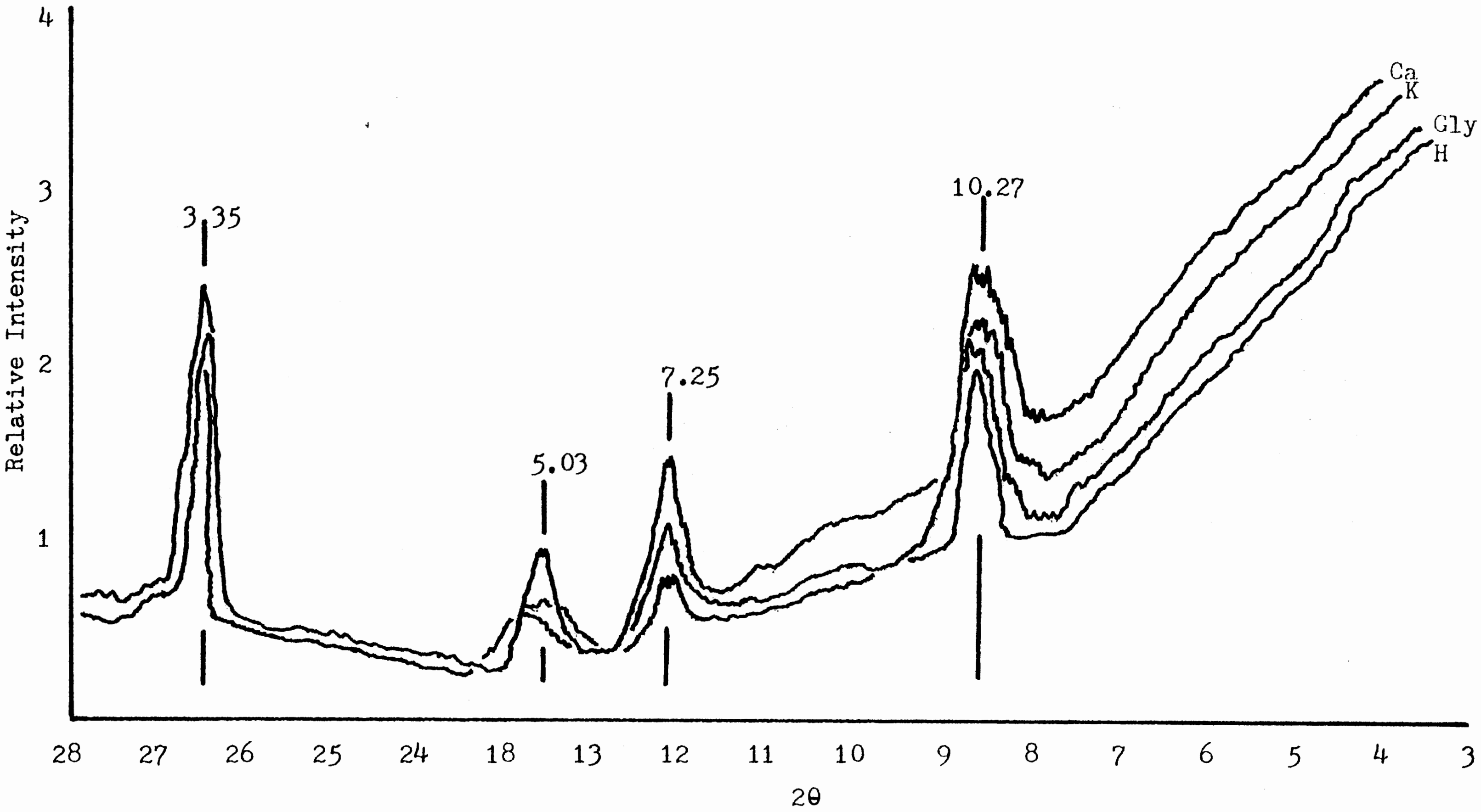

Figure 6. X-ray Diffraction Pattern and d-spacings in Angstroms of the Virgin 15 to 30 cm Coarse Clay Fraction

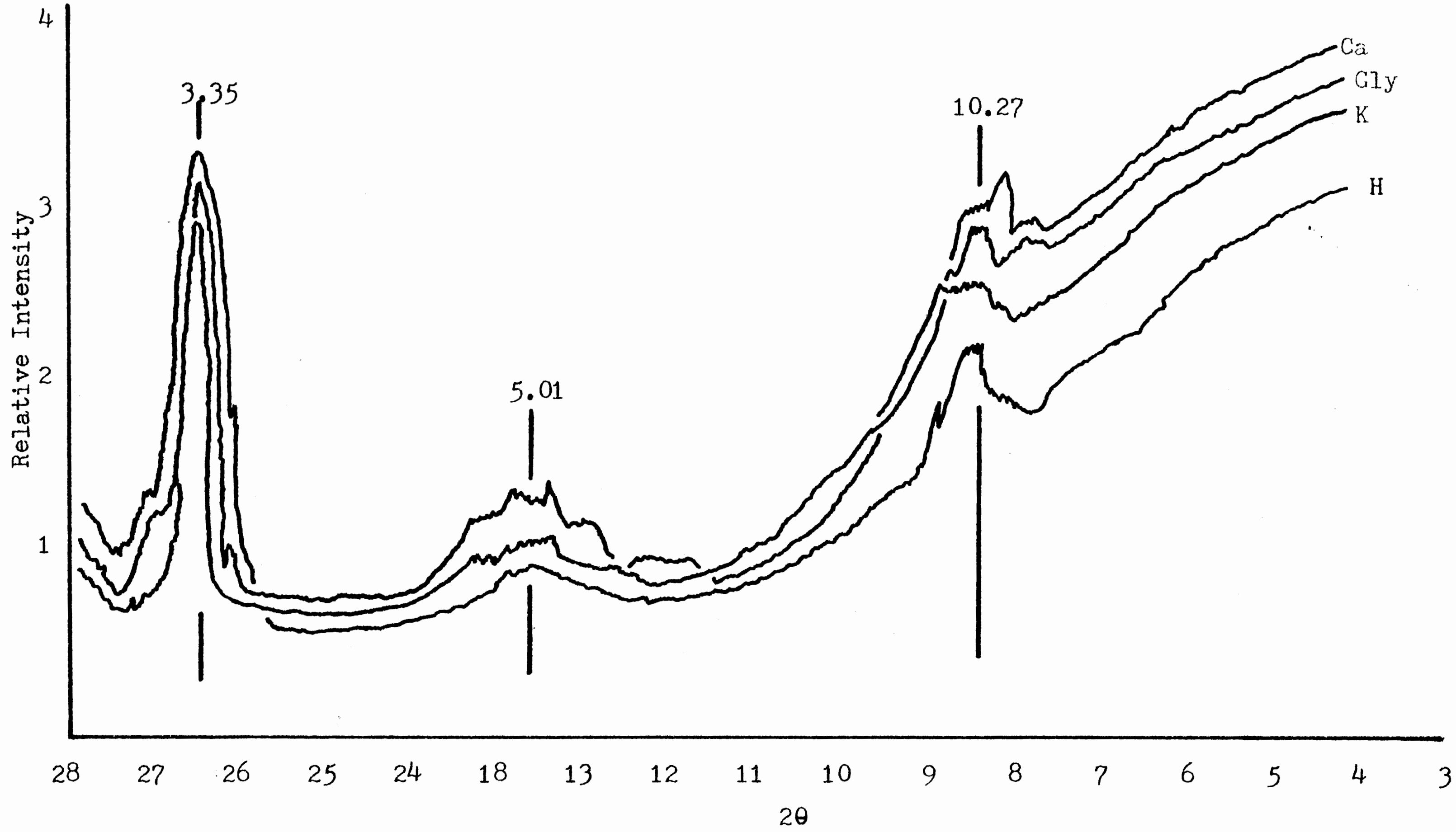

Figure 7. X-ray Diffraction Pattern and d-spacings in Angstroms of the Virgin 15 to 30 cm Fine Clay Fraction

detection of kaolinite was noticed in the Carrier fine clay fraction. The presence of kaolinite could be an indication of the permeability of the silt loam to silty clay loam profile and reflect the ability of kaolinite to fill the soil pores.

X-ray diffraction patterns of the Lahoma soil clay fractions indicate a mixed mineralogy of montmorillonite, vermiculite, hydrous mica (illite), and kaolinite in both the fine and coarse clay fractions (Figures 8, 9).

The Lahoma soil clay fractions showed expansible 14 to 15 A° clay minerals where the 18 A° diffraction peaks due to ethylene glycol solvation was observed in the fine fraction and the 12 A° collapsed peaks due to potassium saturation for both the fine and coarse fractions. The presence of the 13 A° 500°C heat treated peaks in the coarse clay fractions of this and the lower adjacent soil depth indicates the existence of interlayer material (soil chlorite) in the expansible clay minerals. The detection of soil chlorite occurred only at the 60-90 cm depth where most of the clay apparently contained some amorphous material and the relative percent of chlorite was small. The Lahoma soil samples contained expansible clay mineral types suitable for interlayer development. Interlayer detection by routine X-ray diffraction analysis was mainly confined to the 30 to 90 cm subsurface coarse sample with much less found in the fine clay fraction. To support the X-ray diffraction findings and to study the stability and degree of interlayering, the potassium saturated clay samples were mounted on glass slides before being subjected to a multiple heat treatment. The 100°C, 300°C, and 500°C multiple two hour heat treatments resulted in a gradual collapse of the clay mineral structure which signified gradual removal of the interlayer material as detected by shifts from 14 A° to 10 A° with increasing temperatures.

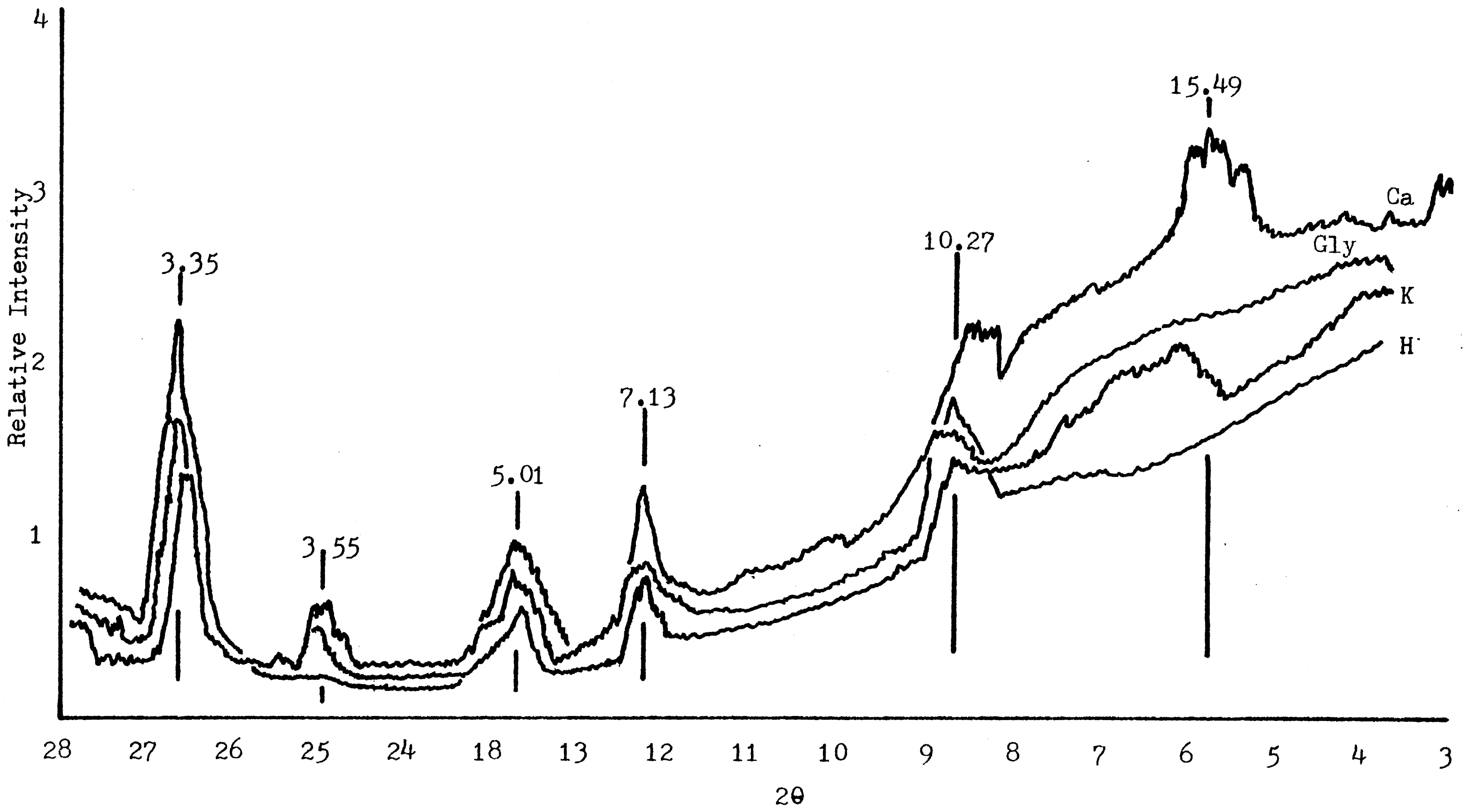

Figure 8. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 45 to 60 cm Coarse Clay Fraction

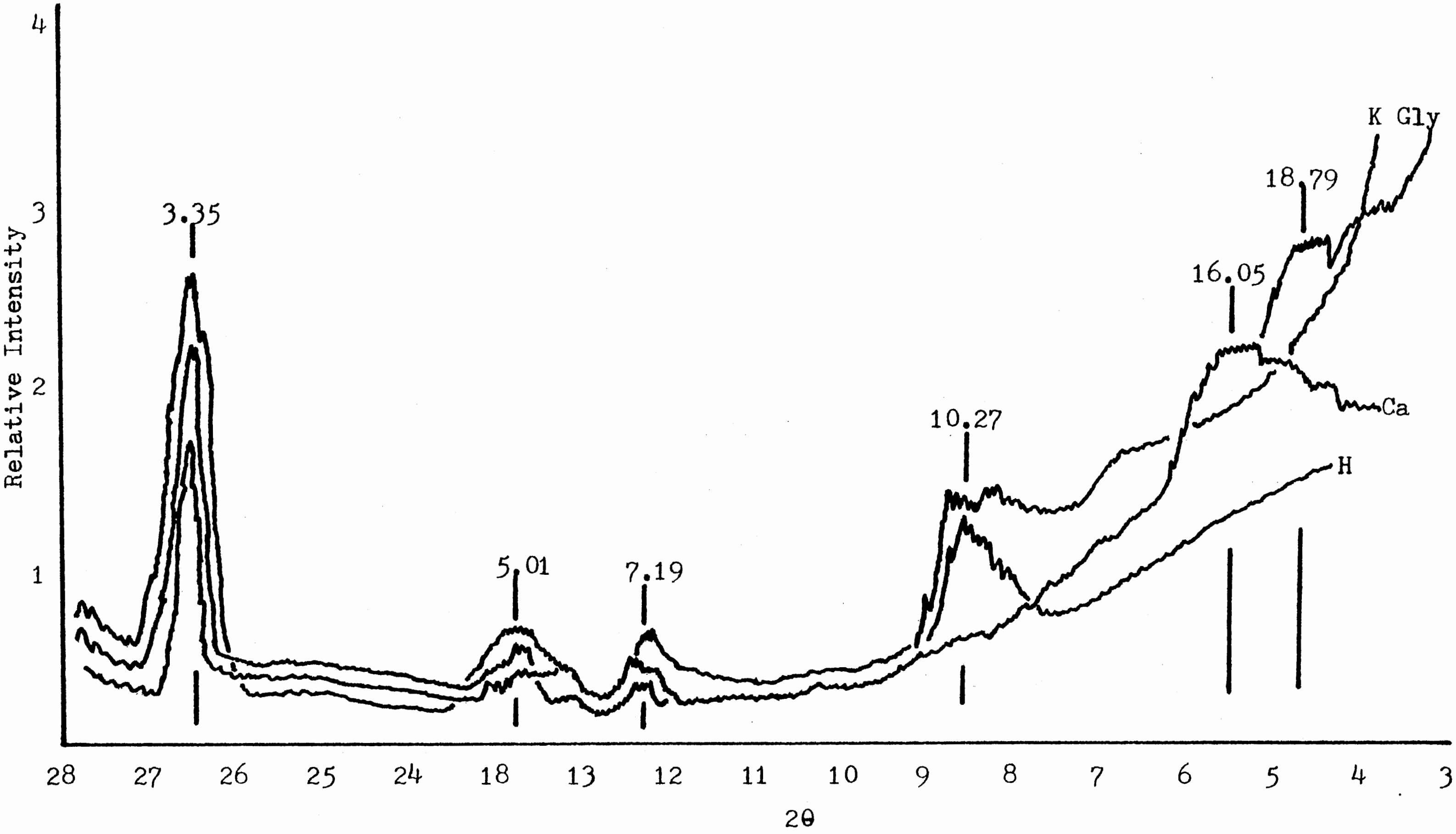

Figure 9. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 45 to 60 cm Fine Clay Fraction

Barnhisel (1977) reports the temperature required to facilitate a partial or complete collapse of the 14 A° peak toward 10 A° can estimate the relatively degree of filling of the interlayer space. Therefore, The higher the temperature required to produce a 14 A° peak shift, the higher the degree of filling. With low hydroxy interlayer levels, a 500°C collapse of exactly 10 A° is not obtainable, but rather a 10.2 to 10.5 A° range. In all the cases studied, the Lahoma 30 to 90 cm interlayer development reflected quantitatively small atolls or island arrangements in the expansible clay minerals (Figures 10, 11, 12, 13, 14, 15).

Grimshaw (1971) states that surface area determination provides an important parameter for studying particle-size distribution, the degree of sorption and the intensity of the chemical reactivity. Surface area determination of a mass of particles involves: (1) external surfaces associated with the geometrical shape, (2) internal surfaces generated by pores and cracks within the particles and (3) lattice departures from the true crystalline arrangement creating internal surfaces. Therefore, the complexity of surface area measurements can explain the widely varying results.

Ethylene glycol monoethyl ether or EGME use facilitates a rapid total surface area determination method for the fine or coarse silicate mineral fractions. In addition to the total surface area determination, the findings reflect the presence of and the sodium citrate removal of the organic matter and Al interlayer. Tinsley and Salam (1961) reported citrate was effective in organic matter removal, especially the reactive humus fraction. Bower and Gschwend (1952) studied the effect of soluble salts, exchangeable cations, and organic matter on the retention of

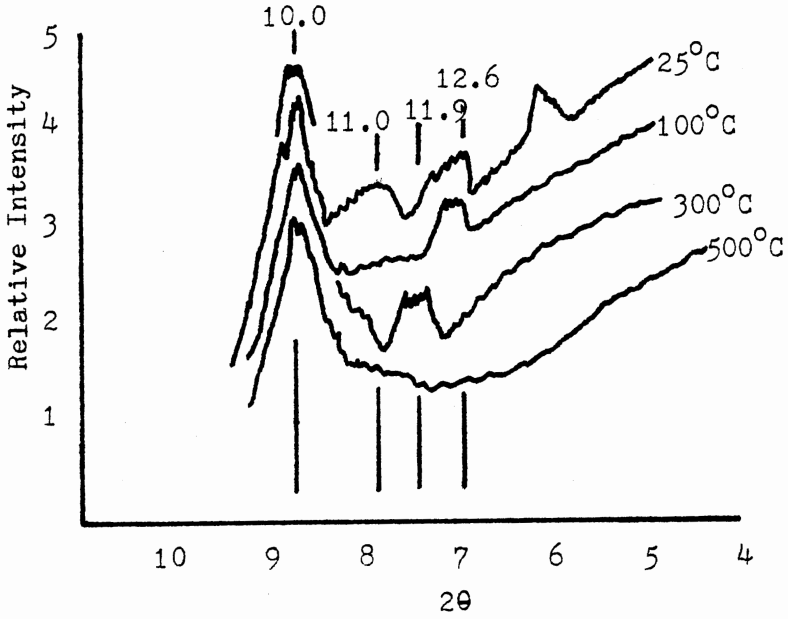

Figure 10. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 30 to 45 cm Interlayer Coarse Clay Fraction

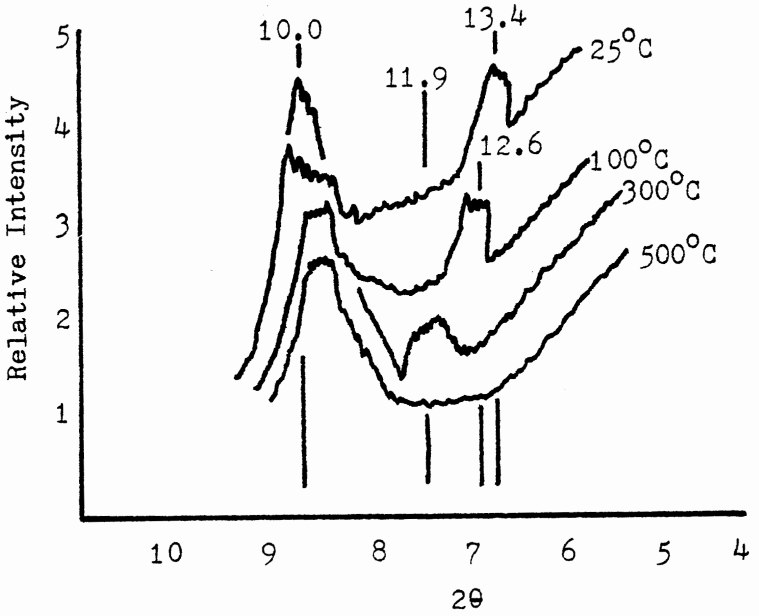

Figure 11. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 30 to 45 cm Interlayer Fine Clay Fraction

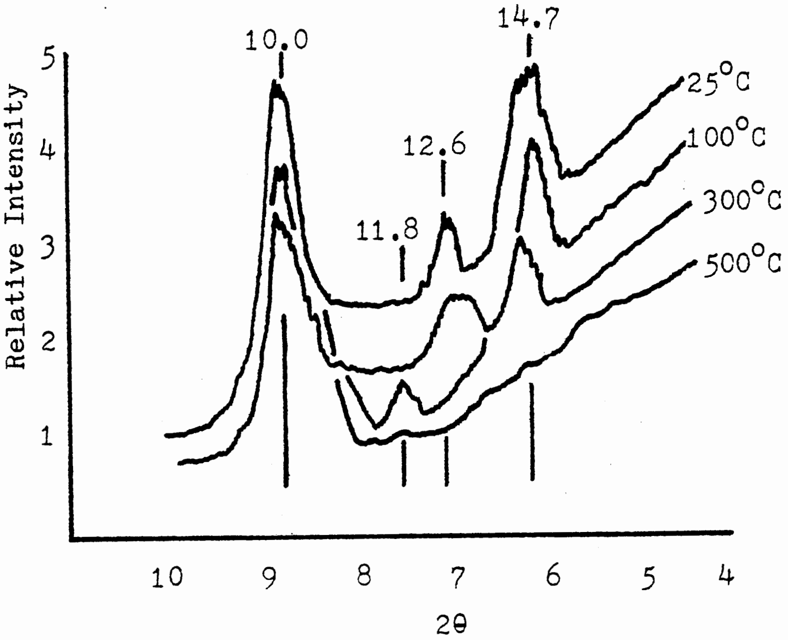

Figure 12. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 45 to 60 cm Interlayer Coarse Clay Fraction

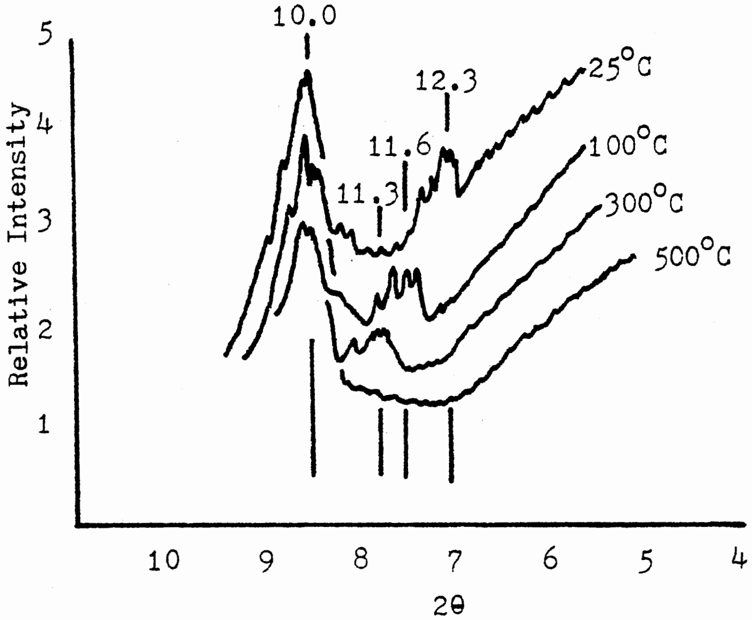

Figure 13. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 45 to 60 cm Interlayer Fine Clay Fraction

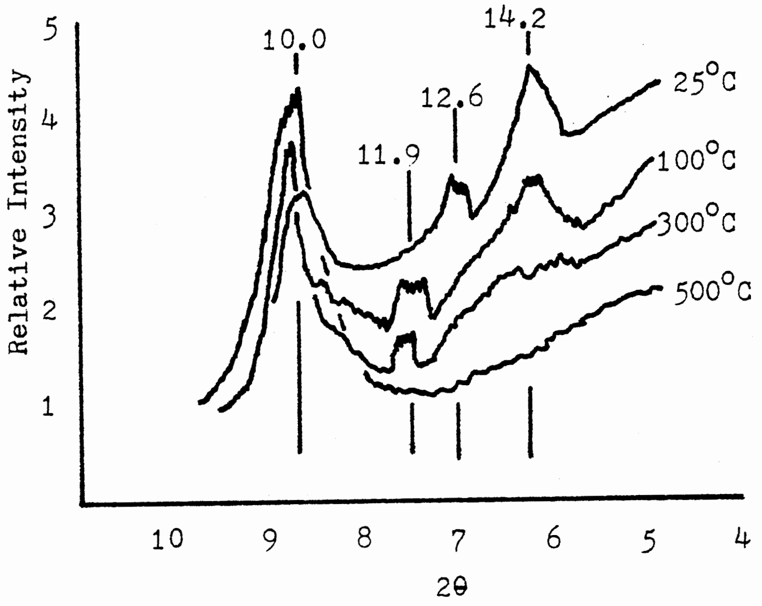

Figure 14. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 60 to 90 cm Interlayer Coarse Clay Fraction

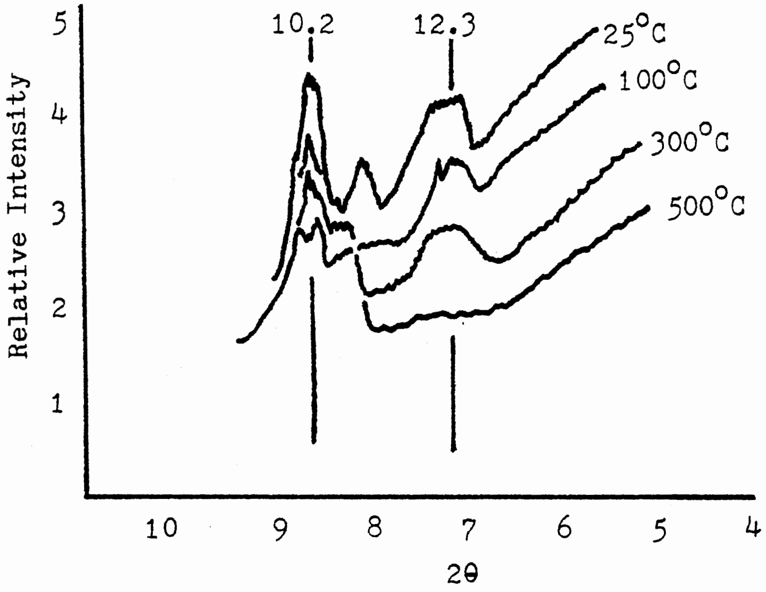

Figure 15. X-ray Diffraction Pattern and d-spacings in Angstroms of the Lahoma 60 to 90 cm Interlayer Fine Clay Fraction

organic molecules by soil and clay complexes. Both soluble salt and exchangeable cation respectively suggested an unaffected and variable retention, with an unaltered or "as is" sample. Also, organic matter substantially increases total retention values which requires a correction factor of about seven square meters per gram in total surface area determinations for each percent of organic matter present in high organic matter surface soils. Therefore, organic matter distribution would be critical in surface area evaluations and could account for the erratic results obtained in this study and in the Bower and Gschwend (1952) study. Most surface area research involves the use of reference clays or soil clays which have been chemically treated to remove cementing agents, such as organic matter, iron oxides, and carbonates. This study entails the use of "as is" soil clays in which the chemical treatment was minimized to insure minimal damage to the existing interlayer material and supporting clay structures. To eliminate the possibility of poor laboratory technique from the complexity of surface are determination, a reference clay series was analyzed in conjunction with the soil clays, which generated comparable surface area values as compared to other studies (Diamond & Kinter, 1958; Mortland & Erickson, 1956) (Kidder and Reed, 1972) (Table II).

Surface area determinations were made on both the fine and coarse clay fractions from the Carrier, Healy, Virgin, and Lahoma soils (Tables III, IV, V, VI). The Carrier, Healy, and Virgin soils are composed of hydrous mica (illite) and kaolinite in the coarse fraction, while hydrous mica (illite) dominates the fine fraction. The Lahoma clay mineralogy was dominated by montmorillonite, vermiculite and chlorite expansible clays and hydrous mica (illite) and kaolinite were the

TABLE II

COMPARISON OF REFERENCE CLAY SURFACE AREAS OBTAINED IN THIS STUDY WITH OTHER RESEARCH STUDIES

Type	Obtained Surface Areas	Other Studies Surface Areas
Montmorillonite (Surface area range: About 500 to more than 700 m^2/g)[1]		
Upton (Wyoming)		
Coarse	534	611[1]
Fine	593	
Camargo (Oklahoma)		
Coarse	603	
Fine	653	650[1,3]
Illite (Surface area range: About 76 to more than 145 m^2/g)[1,2]		
Fithian (Illinois)		
Coarse	79	76[1]
Fine	126	91[1]
Kaolinite (Surface area range: About 14 to more than 30 m^2/g)[1,2]		
Colorado		
Coarse	23	25[1]

[1] Diamond and Kinter (1958)

[2] Mortland and Erickson (1956)

[3] Kidder and Reed (1972)

TABLE III

SODIUM CITRATE EFFECT ON SURFACE AREA DETERMINATIONS OF CARRIER FINE AND COARSE SOIL CLAY FRACTIONS

Depth	Fraction	Before Treatment	After Treatment	Percent Change
		m^2/g	m^2/g	
0-15	Coarse	66	86	30.3
	Fine	410	373	-9.0
15-30	Coarse	91	138	51.6
	Fine	462	641	38.7
30-45	Coarse	104	197	89.4
	Fine	466	732	57.1
45-60	Coarse	174	244	40.2
	Fine	455	747	64.2
60-90	Coarse	115	202	75.7
	Fine	547	762	39.3
Overall Change				
	Coarse			57.4
	Fine			38.1

TABLE IV

SODIUM CITRATE EFFECT OF SURFACE AREA DETERMINATIONS OF HEALY FINE AND COARSE SOIL CLAY FRACTIONS

Depth	Fraction	Before Treatment	After Treatment	Percent Change
		m^2/g	m^2/g	
0-15	Coarse	112	202	80.4
	Fine	297	351	18.2
15-30	Coarse	112	214	91.1
	Fine	445	327	-26.5
30-45	Coarse	131	268	104.6
	Fine	309	427	38.2
45-60	Coarse	152	427	180.9
	Fine	265	300	13.2
60-90	Coarse	125	447	257.6
	Fine	264	413	56.4
Overall Change				
	Coarse			142.9
	Fine			19.9

TABLE V

SODIUM CITRATE EFFECT OF SURFACE AREA DETERMINATIONS OF VIRGIN FINE AND COARSE SOIL CLAY FRACTIONS

Depth	Fraction	Before Treatment	After Treatment	Percent Change
		m^2/g	m^2/g	
0-15	Coarse	53	145	173.6
	Fine	529	522	-1.3
15-30	Coarse	217	218	.5
	Fine	273	551	101.8
30-45	Coarse	118	279	136.4
	Fine	367	765	108.4
45-60	Coarse	131	214	63.4
	Fine	323	762	135.9
60-90	Coarse	195	344	76.4
	Fine	347	534	53.9
Overall Change				
	Coarse			90.1
	Fine			79.7

TABLE VI

SODIUM CITRATE EFFECT ON SURFACE AREA DETERMINATIONS OF LAHOMA FINE AND COARSE SOIL CLAY FRACTIONS

Depth	Fraction	Before Treatment	After Treatment	Percent Change
		m^2/g	m^2/g	
0-15	Coarse	51	151	196.1
	Fine	429	262	-38.9
15-30	Coarse	74	199	168.9
	Fine	463	312	-32.6
30-45	Coarse	149	108	-27.5
	Fine	502	758	51.0
45-60	Coarse	206	304	47.6
	Fine	392	566	44.4
60-90	Coarse	190	460	142.1
	Fine	363	581	60.1
Overall Change				
	Coarse			105.4
	Fine			16.8

nonexpansible types. The Carrier, Healy, and Virgin coarse clays showed a high overall change which could be attributed to the stability of organic matter and the effect of sodium citrate on weakening the structure and inducing exfoliation with new surface generation. The citrate treatment influences and causes surface removal of amorphous materials, such as hydroxy Al and iron, and organic matter. Carrier, Healy, and Virgin fine clay fractions showed small overall treatment change which could be associated with a complete or partial surface "clean-up" and redistribution of the sodium citrate soluble material. The Lahoma coarse clays high overall change could be attributed to aggregate instability with freeing of reactive sites induced by organic matter removal and interlayer blocking material removal by the sodium citrate treatment of the expansible clay minerals. The Lahoma fine clay fractions showed small overall change which could indicate partial surface removal and redistribution of blocking interlayer material and organic matter. The presence of illuviated less reactive, amorphous complexed fine clay from eluviated horizons, and fragmentized remains from interlayer development, probably contributes significantly to the clay mineral surface area.

Cation exchange capacity (CEC) determinations were performed on the Carrier, Healy, Virgin, and Lahoma fine and coarse soil clay fractions. The Carrier soil profile can be characterized as being high in organic matter with very acidic colloidal surfaces (Table VII). The acidic nature of the surfaces signifies removal of cations due to acid leaching facilitated by the extensive use of fertilizers, such as anhydrous ammonia and ammonium nitrate. Reactive nature of organic matter should create a higher initial CEC and organic matter removal should reduce

TABLE VII

BASIC SOIL PROPERTIES WITH PERCENT SODIUM CITRATE INDUCED CEC CHANGE FOR CARRIER FINE AND COARSE CLAY FRACTIONS

Depth	H_2O pH	KCl pH	Percent O.M.	Clay Fraction	Before Treatment	After Treatment	Percent Change
					meq/100g	meq/100g	
0-15	4.8	3.8	1.6	Coarse	12.7	34.2	169.3
				Fine	48.7	28.8	-40.9
15-30	5.8	4.9	1.5	Coarse	30.7	38.9	26.7
				Fine	34.4	25.5	-25.9
30-45	6.7	5.6	1.2	Coarse	37.1	39.6	6.7
				Fine	35.1	26.4	-24.8
45-60	6.8	5.7	.9	Coarse	32.8	25.7	-21.6
				Fine	30.0	25.8	-14.0
60-90	7.3	5.8	.8	Coarse	31.9	45.0	41.1
				Fine	31.6	17.9	-43.4

CEC, however, the exposed clay mineral surfaces could increase the CEC slightly, resulting in a lower overall percent change in the CEC in the Carrier surface soil fine clay fractions. Substantial to moderate CEC increases should occur upon the removal of organic matter, with the encouragement of new surface exposure due to exfoliation. With depth, time, and microbial activity the organic matter probably develops into a very reactive form, humus. The presence of humus would increase exchange sites, increase the CEC, and with sodium citrate removal a marked reduction creating a negative CEC percent change. The overall change in the Carrier profile reflects a 44 percent increase and a negative 30 percent reduction in the coarse and fine soil clay fractions respectively. The coarse fraction could be linked to aggregation instability resulting from organic matter removal and accelerated exfoliation. The marked reduction of fine fraction CEC could be attributed to organic matter removal, especially the reactive humus fraction.

The Healy soil with a uniform profile distribution of very acidic colloidal particles and with removal of amorphous materials and organic matter removal by sodium citrate treatment showed increased CEC of the coarse fraction (Table VIII). Less reactive exchange sites due to organic matter removal, could account for the reduction experienced in the cation exchange capacity values. The overall 43 percent change in the Healy coarse fraction could reflect aggregation instability and exfoliation, while the negative 12 percent fine fraction change could indicate organic matter and amorphous material removal.

The entire Virgin soil profile has a slightly acidic pH associated with the presence of the colloidal particles reflected by the 3 percent surface soil organic matter and greater than one percent subsurface

TABLE VIII

BASIC SOIL PROPERTIES WITH PERCENT SODIUM CITRATE INDUCED CEC CHANGE FOR HEALY FINE AND COARSE CLAY FRACTIONS

Depth	H_2O pH	KCl pH	Percent O.M.	Clay Fraction	Before Treatment	After Treatment	Percent Change
					meq/100g	meq/100g	
0-15	5.4	4.3	1.3	Coarse	19.7	39.0	98.0
				Fine	30.3	28.3	-6.6
15-30	5.8	4.6	1.3	Coarse	33.3	47.6	43.0
				Fine	41.1	31.4	-23.6
30-45	6.6	5.4	1.2	Coarse	36.2	45.0	24.3
				Fine	34.0	30.3	-10.9
45-60	6.9	5.6	1.0	Coarse	31.0	43.7	41.0
				Fine	33.2	33.0	-.6
60-90	7.0	5.8	.8	Coarse	33.8	35.9	6.2
				Fine	35.2	28.2	-19.9

organic matter levels (Table IX). The pH of the Virgin soil profile from the surface to 90 cm indicates that most of the exchange sites should be occupied by basic cations and the basic cation removal with the accompanying exposed exchange sites as compared with the heavily fertilized Carrier, Lahoma, and Healy soils can not be applied to this Virgin soil. Data reported in Table X compares the water and salt pH treatments of the Virgin, Carrier, Lahoma, and Healy soils, in which one-half pH unit treatment differential exist in the Virgin soil profile, while at least one to one and a half unit treatment differential exist in the Carrier, Lahoma, and Healy soils. The degree of basic cation removal in the Virgin soil reflects the natural leaching as compared to the Carrier, Lahoma, and Healy soils where more intense acid leaching is associated with the combination of acid forming fertilizers and rainwater. The Virgin, rainwater leached soil, will contain less reactive organic matter, therefore sodium citrate removal should weaken coarse particle aggregation and provide for surface "clean-up" of the fine particles resulting in increased CEC values following the sodium citrate treatment.

The extensive use of acid forming fertilizers on the low organic matter Lahoma soil could account for the surface removal of basic cations, aid in the removal of reactive clays to lower depths, and provide an ideal environment for readily available and sometimes toxic levels of Al in the soil solution (Table XI). Lime additions to the Lahoma soil would increase the pH and allow for the precipitation of Al. The Carrier soil, another soil with toxic levels of Al to wheat, had substantially higher organic matter levels which could complex the Al creating a slower release which might control the toxic Al problem.

TABLE IX

BASIC SOIL PROPERTIES WITH PERCENT SODIUM CITRATE INDUCED CEC CHANGE FOR VIRGIN FINE AND COARSE CLAY FRACTIONS

Depth	H_2O pH	KCl pH	Percent O.M.	Clay Fraction	Before Treatment	After Treatment	Percent Change
					meq/100g	meq/100g	
0-15	6.4	6.2	3.2	Coarse	25.1	47.3	88.4
				Fine	51.0	81.2	59.2
15-30	6.4	6.1	1.7	Coarse	21.0	48.6	131.4
				Fine	39.4	64.8	64.5
30-45	6.4	6.1	1.5	Coarse	33.2	47.2	42.2
				Fine	31.2	44.6	42.9
45-60	7.3	6.1	1.2	Coarse	36.0	39.4	9.4
				Fine	30.5	47.0	54.1
60-90	6.9	6.3	1.1	Coarse	39.8	42.9	7.8
				Fine	29.8	41.5	39.3

TABLE X

WATER AND KCl pH ON THE VIRGIN, CARRIER, LAHOMA, AND HEALY SOIL DEPTHS

Depth	pH	Virgin	Carrier	Lahoma	Healy
0-15	H_2O	6.4	4.8	4.9	5.4
	KCl	6.2	3.8	3.8	4.3
15-30	H_2O	6.4	5.8	5.7	5.8
	KCl	6.1	4.9	4.3	4.6
30-45	H_2O	6.4	6.7	7.4	6.6
	KCl	6.1	5.6	6.3	5.4
45-60	H_2O	7.3	6.8	8.2	6.9
	KCl	6.1	5.7	7.0	5.6
60-90	H_2O	6.9	7.3	8.5	7.0
	KCl	6.3	5.8	7.1	5.8

TABLE XI

BASIC SOIL PROPERTIES WITH PERCENT SODIUM CITRATE INDUCED CEC CHANGE FOR LAHOMA FINE AND COARSE CLAY FRACTIONS

Depth	H_2O pH	KCl pH	Percent O.M.	Clay Fraction	Before Treatment	After Treatment	Percent Change
					meq/100g	meq/100g	
0-15	4.9	3.8	1.0	Coarse	45.9	40.7	-11.3
				Fine	39.4	29.6	-24.9
15-30	5.7	4.3	.6	Coarse	42.5	46.8	10.1
				Fine	38.3	35.4	-7.6
30-45	7.4	6.3	.5	Coarse	45.2	30.4	-32.7
				Fine	35.5	32.0	-9.9
45-60	8.2	7.0	.6	Coarse	43.5	26.8	-38.4
				Fine	44.7	22.4	-49.9
60-90	8.5	7.1	.7	Coarse	44.5	31.9	-28.3
				Fine	47.0	27.2	-42.1

Removal of basic cations in the acidic Carrier and Lahoma surface soil samples reflects the availability of exchange sites by the higher initial CEC values. Reactive organic matter removal would expose less exchange sites which would account for the negative CEC percent change. With depth, organic matter transformation generates the reactive humus fraction. The existence of humus provides additional exchange sites, which like the existing exchange sites, are readily occupied by the leached cations resulting in an overall shortage or reduction in available exchange sites. The exchange sites due to humus and amorphous material still provides more sites than the blocked and occupied clay mineral surfaces according to the lower CEC values after sodium citrate treatment.

The generally lower than expected CEC values before and after sodium citrate treatment of the expansible clay of the Lahoma subsurface samples could reflect the presence and interaction of organic matter, interlayer Al, hydroxy Al polymers, and iron, on the internal and external clay surfaces. The amorphous material and clay matrix could have been affected sufficiently by the sodium citrate treatment in increasing crystallinity and reducing the quantity of amorphous materials.

Presence of detectable interlayer Al in the Carrier, Healy, and Virgin soil clay fractions appears doubtful from the X-ray diffraction findings. Diffraction results revealed the existence of the less expansible clays, such as hydrous mica and kaolinite, with an absence of expansible clays such as montmorillonite and vermiculite. The overall peak characteristics of the X-ray diffraction patterns suggest the presence of amorphous material, such as hydroxy Al and/or iron polymers, and organic matter which may or may not be complexed with Al. Only the Lahoma soil fractions suggest the existence of expansible clay minerals, such as vermiculite, montmorillonite, and chlorite, in addition to the presence of less expansible kaolinite and hydrous mica (illite) clays. The overall X-ray diffraction peak characteristics from the Lahoma soil clay fractions suggests the existence of amorphous material, which could have been caused by the sodium citrate treatment.

The quantitative and qualitative condition of the amorphous material is critical in the sodium citrate reactivity towards partial or complete removal of amorphous and interlayer material. The literature reviews by

Mitchell et al. (1964), Rich (1968) and Barnhisel (1977) recommend a multitude of extraction methods for the removal of interlayer Al and amorphous material from expansible aluminosilicate minerals. The adopted and widely recommended sodium citrate method for removal of interlayer Al can be effective in attacking and removing the amorphous material according to Mitchell et al. (1964). Tinsley and Salam (1961) reported on the removal of organic matter and demonstrated the effectiveness of citrate. Therefore, the sodium citrate extractable or interlayer Al data for interlayer Al for the Carrier, Healy, and Virgin soil clays appears justified by the ability of the sodium citrate to extract amorphous Al and organic matter from the reactive clay surface environment (Table XII).

Generally, the overall acidic nature and high organic matter levels associated with these surface soils probably were responsible for the lack of interlayer Al. Subsurface soil samples show an absence of interlayer Al in these soils. The presence of Al interlayers at the lower depths, 30 to 90 cms, of the Lahoma soil could have resulted from a past history of desirable interlayer development characteristics which were altered over time by the soil components involvment in the eluviation and illuviation process.

Detectable sodium citrate extractable Al differential between the Carrier and Lahoma soils could reflect the ability of sodium citrate to remove amorphous materials and possible higher levels of organic matter material from the Carrier soil clay surface environment. The erratic sodium citrate extractable Al findings for the Healy and Virgin soil clay reflects the ability of citrate to induce changes in the reactive surface environment of the soil silicate minerals (Table XII).

TABLE XII

SODIUM CITRATE EXTRACTABLE ALUMINUM FROM CARRIER, LAHOMA, HEALY AND VIRGIN SOIL CLAYS AT RESPECTIVE PROFILE DEPTHS

Depth	Clay Fraction	Carrier	Lahoma	Healy	Virgin
		meq/g clay	meq/g clay	meq/g clay	meq/g clay
0-15	Coarse	4.2	1.9	3.1	4.3
	Fine	1.3	1.8	2.4	1.6
15-30	Coarse	2.2	1.9	2.7	3.3
	Fine	4.3	2.2	3.5	2.0
30-45	Coarse	4.8	4.0	2.1	2.9
	Fine	3.5	2.2	6.4	3.6
45-60	Coarse	5.7	3.4	2.4	1.5
	Fine	4.0	1.8	6.0	2.3
60-90	Coarse	1.6	2.0	1.9	1.4
	Fine	4.7	4.0	2.6	1.8

Exchangeable cation data from the Carrier, Lahoma, Healy, and Virgin soils is reported in the Appendix (Table XIX) and the data obtained from the Carrier and Lahoma soil was subjected to statistical analysis (Tables XIII, XVII, XVIII). The analysis involved testing differences between locations, depths, and location vs depth interaction. Locations were tested by quadrant within location differences. Depths and location and depth interaction were tested quadrant by depth within location differences. The statistical analysis revealed significant differences in locations, depths, and location and depth interaction for potassium chloride and water soluble Al, water soluble

TABLE XIII

MEAN SQUARES AND PROBABILITY OF F VALUES FROM ANALYSIS OF VARIANCE ON CARRIER AND LAHOMA SOILS

Source	Degrees of Freedom	KCl Al		H_2O Al		H_2O Ca		H_2O Mg		H_2O Na	
		Ms	P	Ms	P	Ms	P	Ms	P	Ms	P
LOC	1	.9831	.0416	.5535	.0179	.0001	.9144	.0147	.2276	.1809	.1735
QUAD (LOC)	6	.1494		.0533		.0132		.0082		.0765	
DEPTH	4	1.9901	.0001	.0335	.0060	.0221	.0002	.0115	.0001	.0040	.5265
QUAD*DEPTH (LOC)	24	.0568		.0070		.0023		.0009		.0044	
LOC*DEPTH	4	.4154	.0008	.0341	.0056	.0063	.0580	.0015	.2097	.0009	.9238
QUAD*DEPTH (LOC)	24	.0568		.0070		.0023		.0009		.0044	

TABLE XIII (Continued)

Source	Degrees of Freedom	H_2O K		H_2O pH		KCl pH		Pct Clay	
		Ms	P	Ms	P	Ms	P	Ms	P
LOC	1	.0080	.0621	1.9404	.6273	9.8568	.0504	6974.	.0062
QUAD (LOC)	6	.0015		2.0704		1.6769		396.9	
DEPTH	4	.0141	.0001	34.31	.0001	25.1183	.0001	1700.	.0001
QUAD*DEPTH (LOC)	24	.0001		.1804		.2070		26.34	
LOC*DEPTH	4	.0055	.0001	1.1643	.0014	1.9851	.0002	344.4	.0001
QUAD*DEPTH (LOC)	24	.0001		.1804		.2070		26.34	

TABLE XIII (Continued)

Source	Degrees of Freedom	NH_4 Ca		NH_4Mg		NH_4 Na		NH_4 K		Pct OM		CEC	
		Ms	P	Ms	P	Ms	P	Ms	P	Ms	P	Ms	P
LOC	1	3.1700	.3085	1.3213	.7686	.9096	.5060	.0234	.4093	.4470	.5177	.2880	.9435
QUAD (LOC)	2	1.7238		12.4782		1.3144		.0217		.6067		46.9220	
DEPTH	4	41.3398	.0004	10.3756	.0017	.4393	.3718	.0438	.0085	.2320	.0082	79.6742	.0019
QUAD*DEPTH (LOC)	8	1.7284		.7589		.3577		.0058		.0303		6.1707	
LOC*DEPTH	4	2.5933	.2889	.0920	.9684	.2859	.5593	.0073	.3584	.0493	.2579	4.5942	.5893
QUAD*DEPTH (LOC)	8	1.7284		.7589		.3577		.0058		.0303		6.1707	

potassium, soil-salt pH, and percent clay.

Higher surface and subsurface concentrations of exchangeable Al occurred in the Lahoma soil compared to the Carrier soil. The high surface concentration of .5 to .3 meq/100g of exchangeable Al extended down to 30 cm depth with substantial reduction of concentration to .06 to .04 meq/100g in the lower depths (45-90 cms). The water soluble Al was uniform in concentration (.01 meq/100g) throughout the Carrier profile, while a substantially higher concentration (.05 to .20 meq/100g) occurred with increasing depth in the Lahoma soil. There was a gradual increase of .01 to .02 meq/100g of water soluble Al occurring with each successive depth in both soils.

There were comparable concentrations of water soluble potassium decreasing with depth for both soils except for the higher concentration at the 0-30 cm surface depth for the Carrier soil. There was a reduction in concentration of water soluble potassium with depth. The soil-salt pH increased with depth in the Carrier soil, however, the soil was acid throughout. A substantially higher percent of clay was detected in the Carrier soil, however, both soils were three to six percent higher in clay with successive increase in depth (Tables XX, XXII).

Statistical analysis showed significant differences in depths and location and depth interaction for water soluble calcium and soil-water pH. Water soluble calcium increased more with depth for the Lahoma soil than for the Carrier soil. Concentration of water soluble calcium (.08 to .09 meq/100g) extended down to the 30 cm depth, with .13 meq/100g concentration in the remaining depths. Higher soil-water pH values were associated with the Carrier, however, both soils possessed very acid surface soil with a gradual increase in pH to a pH 7 at the 60-90 cm depth.

Percent base saturation of the Carrier, Lahoma, and Healy soils reveals the effects of acid leaching probably due to intensive use of acid forming fertilizers which resulted in the removal of basic cations from the surface soil with deposition in the subsurface soil (Table XIV). The slightly acidic to neutral Virgin soil pH reflects less acidic leaching.

TABLE XIV

PERCENT BASE SATURATION FOR CARRIER, LAHOMA, HEALY AND VIRGIN SOIL DEPTHS

Soil	0-15 cm	15-30 cm	30-45 cm	45-60 cm	60-90 cm
Carrier	71.2	94.6	96.1	99.9	99.9
Lahoma	85.3	86.4	96.8	97.5	95.2
Healy	74.6	82.8	94.3	91.6	96.9
Virgin	93.9	93.4	92.6	93.1	95.9

Carrier and Lahoma soils showed significant differences with depth for water soluble magnesium, ammonium acetate exchangeable calcium, magnesium, and potassium, percent organic matter, and cation exchange capacity. Gradually increasing concentrations of water soluble magnesium with depth occurred in the Carrier soil, while similiar but lower concentrations occurred in the Lahoma soil. There was a gradual .01 meq/100g increase in concentration of water soluble magnesium with each successive depth. Alternating lower and higher concentrations of exchangeable calcium and magnesium was observed between the Carrier and Lahoma soils with depth and the Carrier soil was higher in exchangeable potassium with depth. The exchangeable calcium and magnesium increased with depth. The exchangeable potassium decreased with depth. The Carrier soil profile contained a slightly higher percentage of organic matter, ranging from 1.5 to .9 percent, when compared to the Lahoma soil of 1.4 to .8 percent. A reduction in organic matter with depth occurred in both soils, while maintaining at least one percent organic matter down to the 60 cm for the Carrier soil and 30 cm for the Lahoma soil. The cation exchange capacity for the Carrier and Lahoma soils increased with depth, but similiarities ended with the Carrier soil having a higher CEC in the 15-45 cm depths and lower CEC in the 45-90 cm depths than the Lahoma soil.

Statistical analysis revealed no significant differences between the water soluble and exchangeable sodium in the Carrier and Lahoma soils. Identical water soluble sodium results were obtained for the Carrier and Lahoma soils showing a slight increase with depth. The exchangeable sodium increased with depth for both soils and the Lahoma soil was slightly higher in sodium than the Carrier soil.

The cropland of the north central part of Oklahoma has been intensively cultivated and heavily fertilized with acid forming fertilizers, such as ammonium nitrate and anhydrous ammonia, for at least thirty years. To understand the long term affect of acid forming fertilizers on the breakdown and release of soil components, an extensive leaching program was conducted on the Healy and Virgin soils. The data obtained from the two leaching programs was of considerable interest. The two leaching regimes were; dilute nitric acid, and dilute ammonium nitrate solutions.

The first visual signs of soil deterioration with nitric acid occurred after the completion of the third leaching increment, while the same visual signs did not occur with ammonium nitrate until completion of the sixth leaching increment. The phenomenon involved extensive surface cracking on drying with curling along the opening edges. Therefore, major physical and chemical changes appeared to occur earlier with the acid leaching as compared to the ammonium nitrate leaching.

The extensive leaching with fertilizer and acid appeared to be a successful laboratory technique for reproducing the effect of many years of fertilizer application. According to the before and after leaching pH table, the extensive leaching produced pH values comparable to the field pH values (Table XV). Nitric acid leaching resulted in the near neutral Virgin soil pH being reduced to very acidic state and was comparable to the highly fertilized field soils. A gradual increase in acidity occurred when ammonium nitrate solutions were leached through the soil.

The tables and graphs summarize the effect of both ammonium nitrate and nitric acid on the removal of basic soil constituents (Table XXIII, Figures 16-35). In all cases, acid removal of basic soil constituents was more effective than ammonium nitrate. Excellent correlation with linear data was observed for the one hundred pound increments of nitrogen as soil component removal (Table XVI).

Removal of Al from the Healy soil was about twenty-nine times greater for HNO_3 at both the beginning and ending of leaching when

TABLE XV

BEFORE AND AFTER pH VALUES OF NH_4NO_3 AND HNO_3 ACID LEACHING TREATMENTS ON THE HEALY AND VIRGIN SOIL

Depth (cm)	Initial pH	After HNO_3 Treatment pH	After NH_4NO_3 Treatment pH
Healy			
0-15	5.38	3.20	5.20
15-30	5.79	3.15	5.55
30-45	6.58	3.20	5.50
45-60	6.85	3.10	5.95
60-90	6.99	3.10	6.30
Virgin			
0-15	6.36	3.00	5.10
15-30	6.44	3.10	5.60
30-45	6.39	3.20	5.70
45-60	7.26	3.15	5.75
60-90	6.85	3.15	6.00

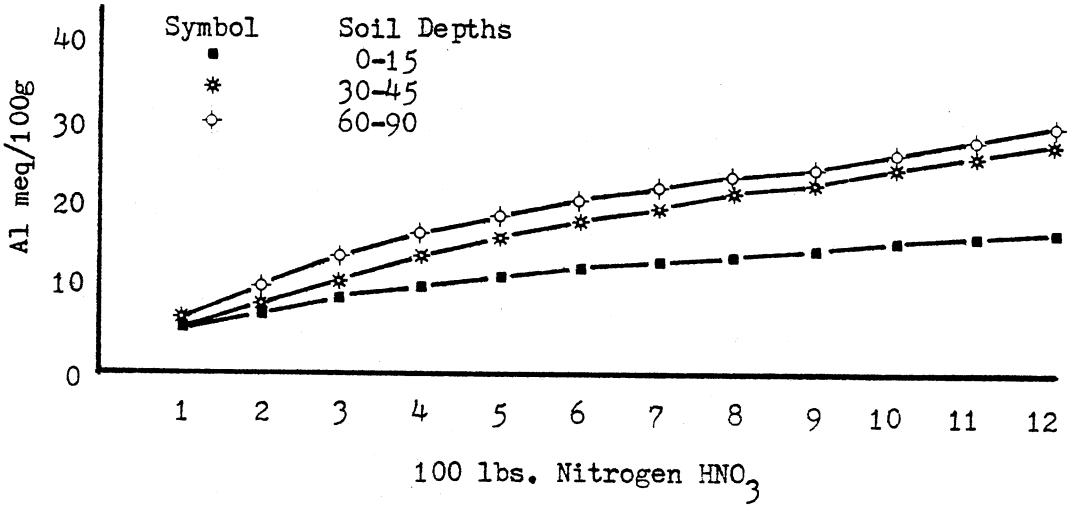

Figure 16. Al Removal from Healy Soil by HNO_3 Leachings

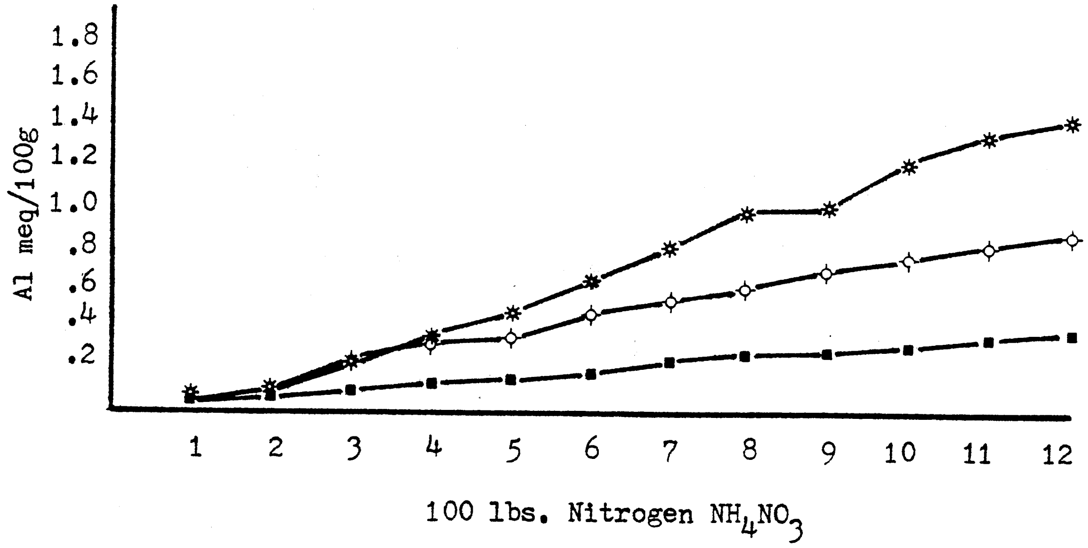

Figure 17. Al Removal from Healy Soil by NH_4NO_3 Leachings

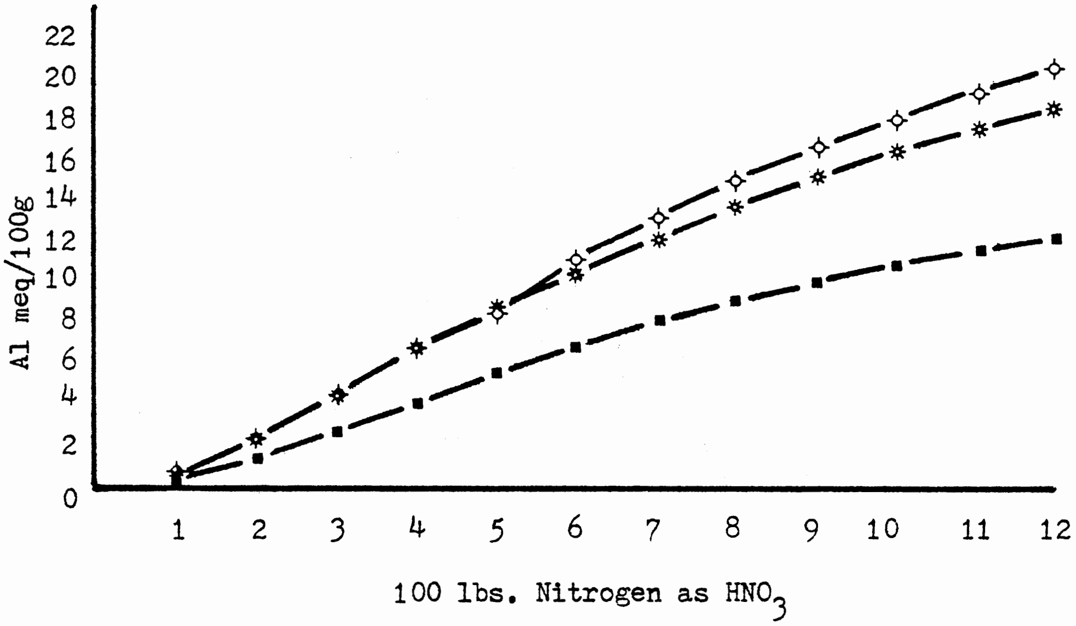

Figure 18. Al Removal from Virgin Soil by HNO_3 Leaching

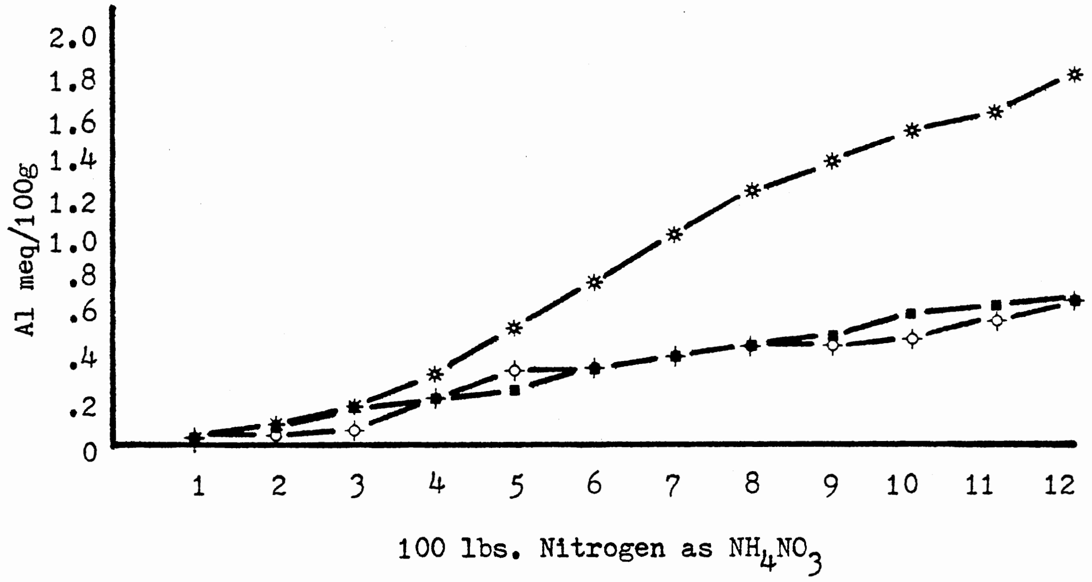

Figure 19. Al Removal from Virgin Soil by NH_4NO_3 Leaching

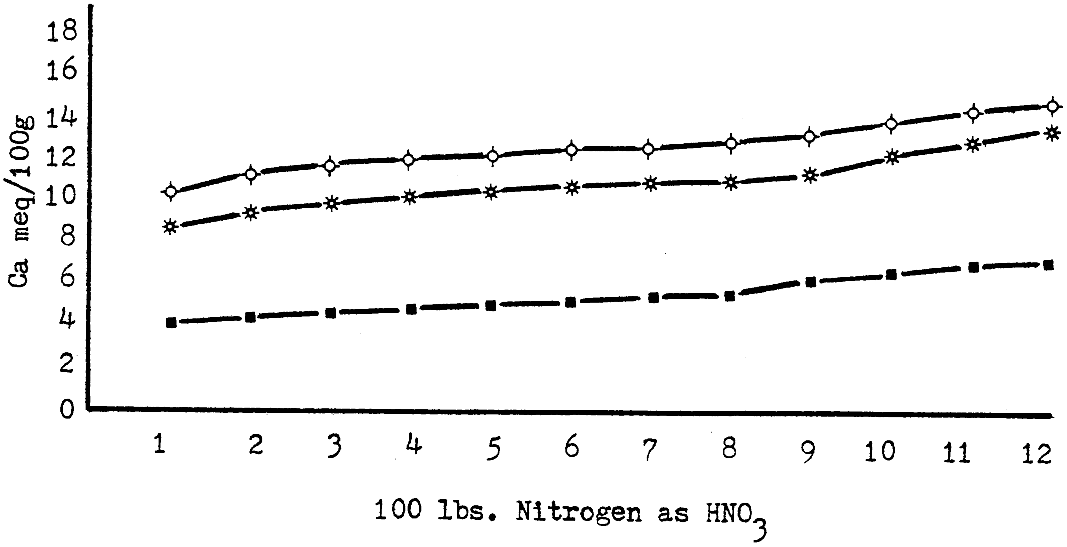

Figure 20. Ca Removal from Healy Soil by HNO_3 Leaching

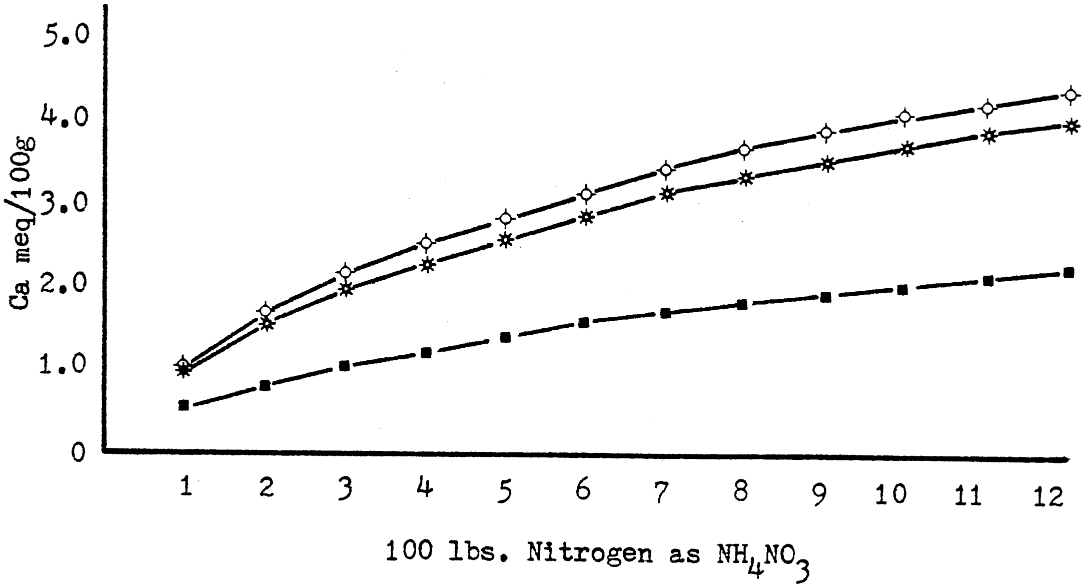

Figure 21. Ca Removal from Healy Soil by NH_4NO_3 Leaching

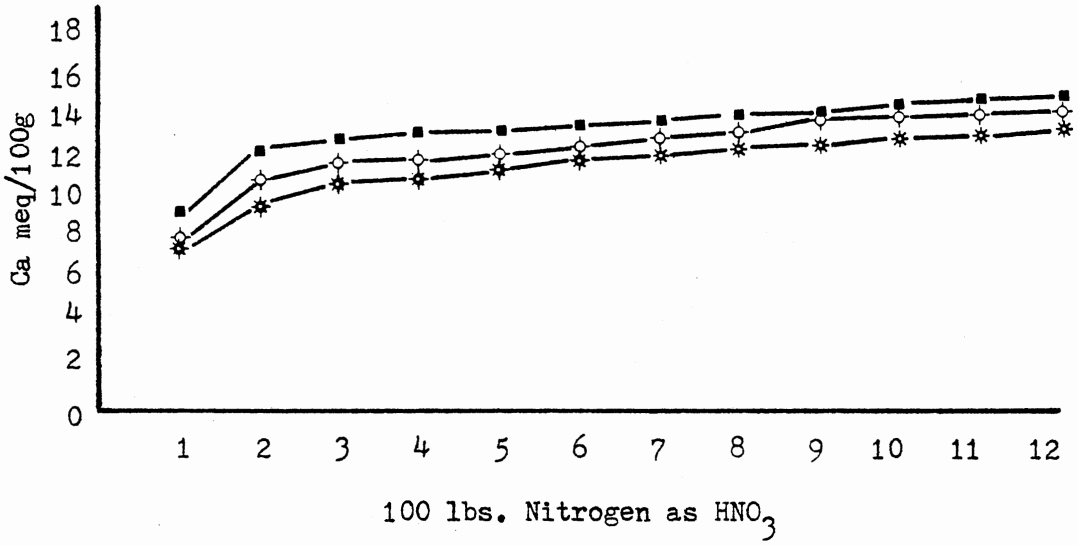

Figure 22. Ca Removal from Virgin Soil by HNO_3 Leaching

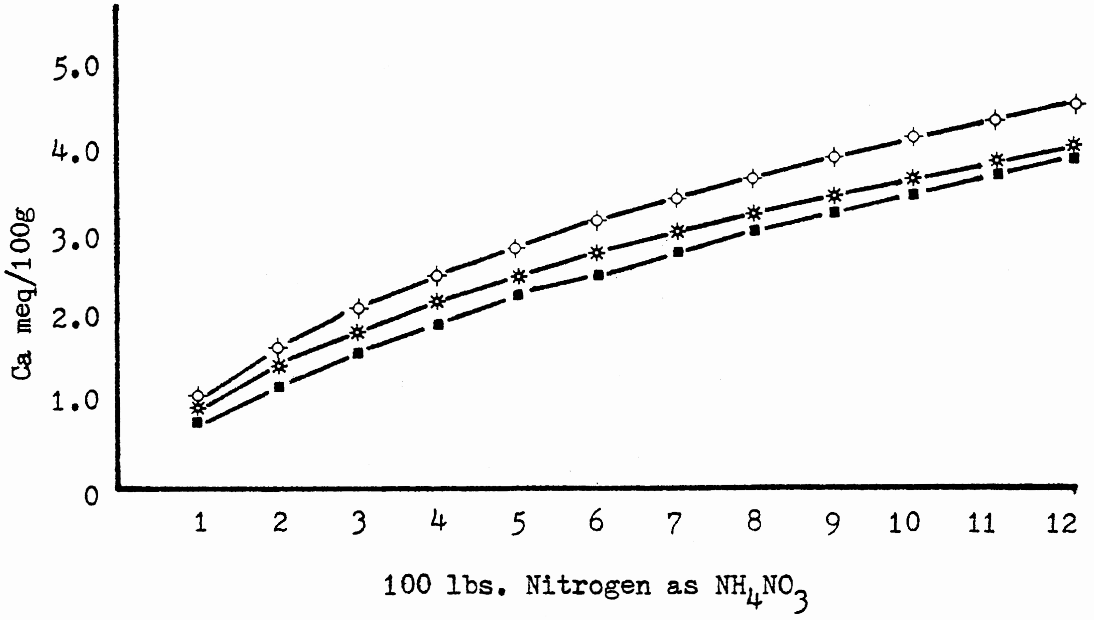

Figure 23. Ca Removal from Virgin Soil by NH_4NO_3 Leaching

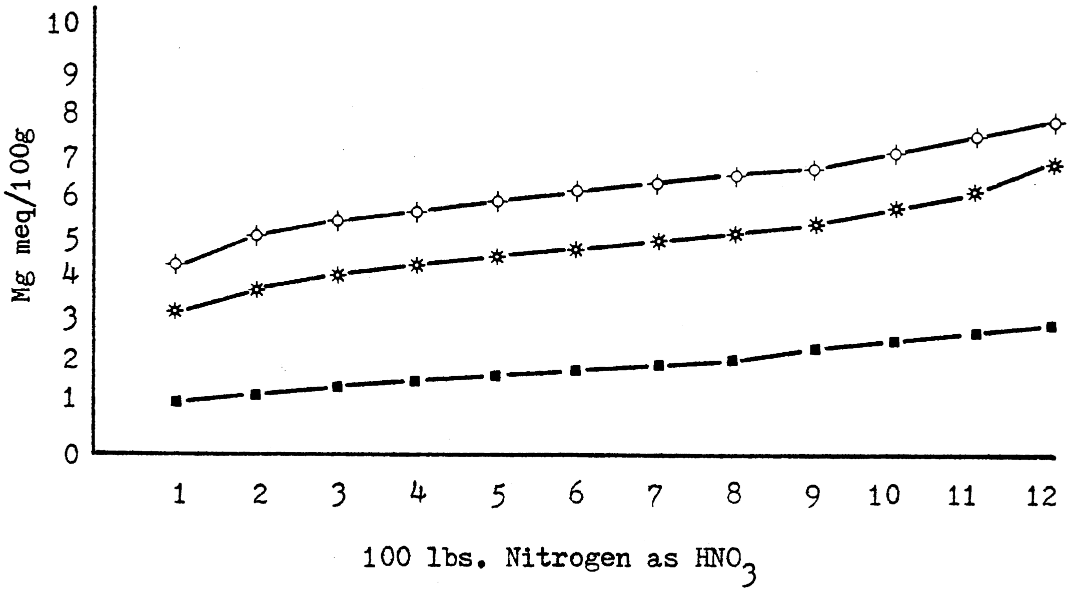

Figure 24. Mg Removal from Healy Soil by HNO_3 Leaching

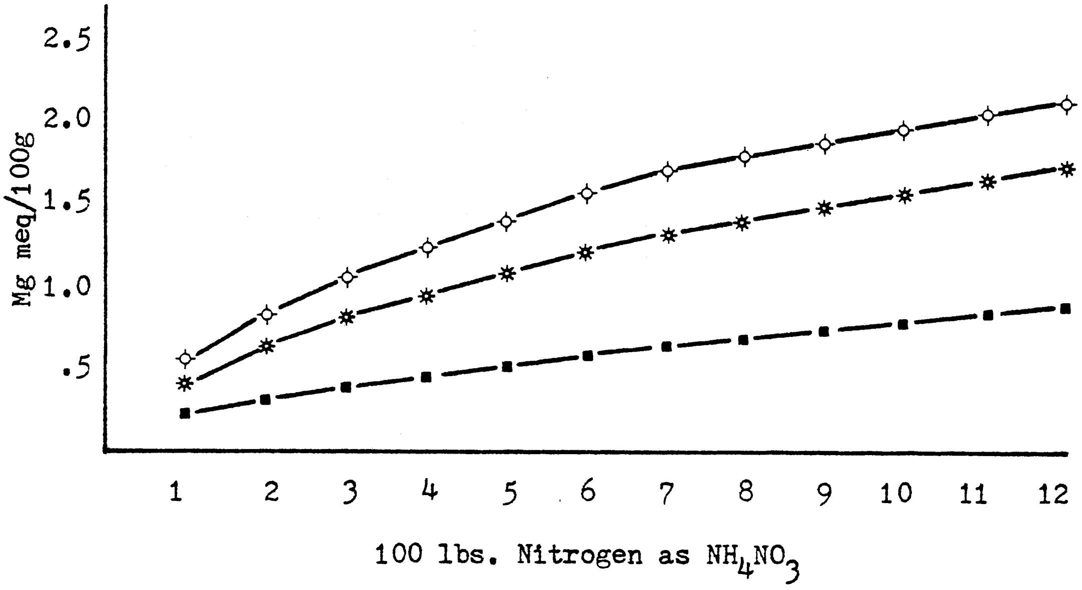

Figure 25. Mg Removal from Healy Soil by NH_4NO_3 Leaching

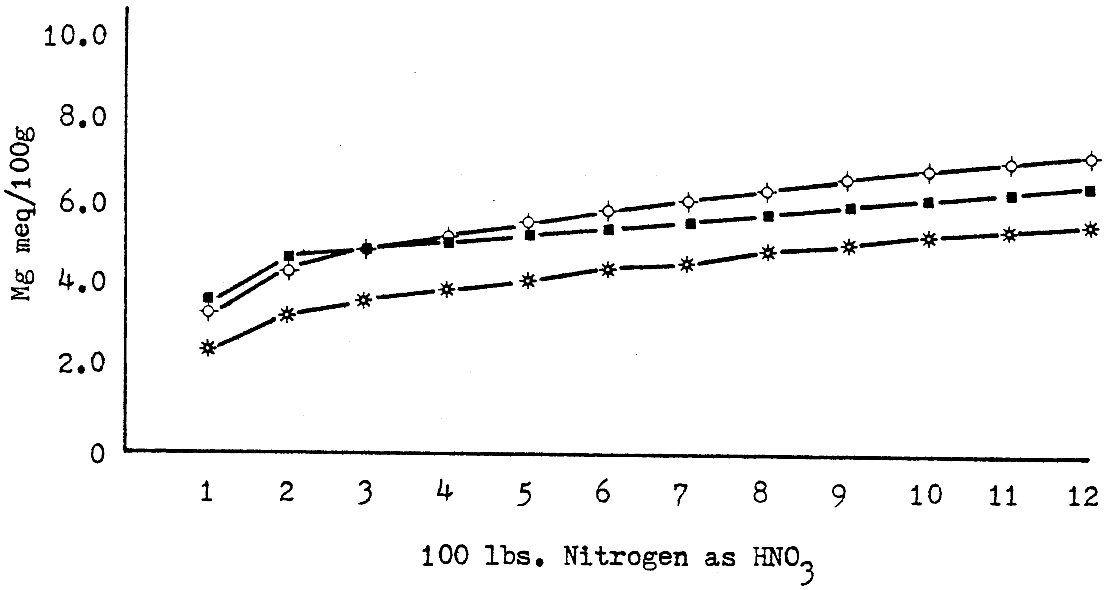

Figure 26. Mg Removal from Virgin Soil by HNO_3 Leaching

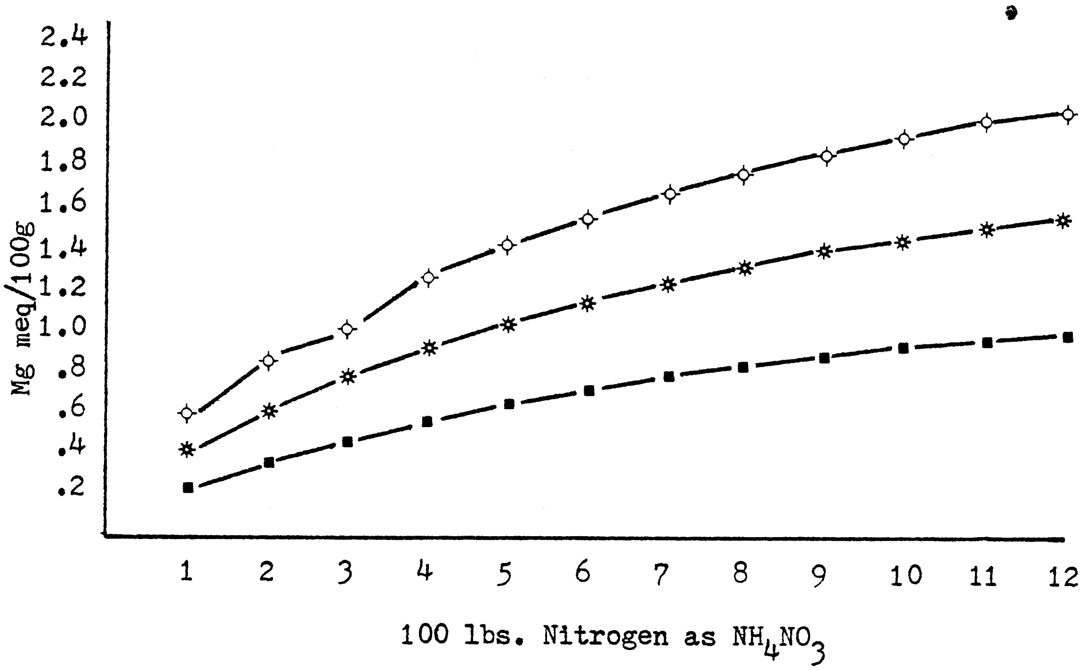

Figure 27. Mg Removal from Virgin Soil by NH_4NO_3 Leaching

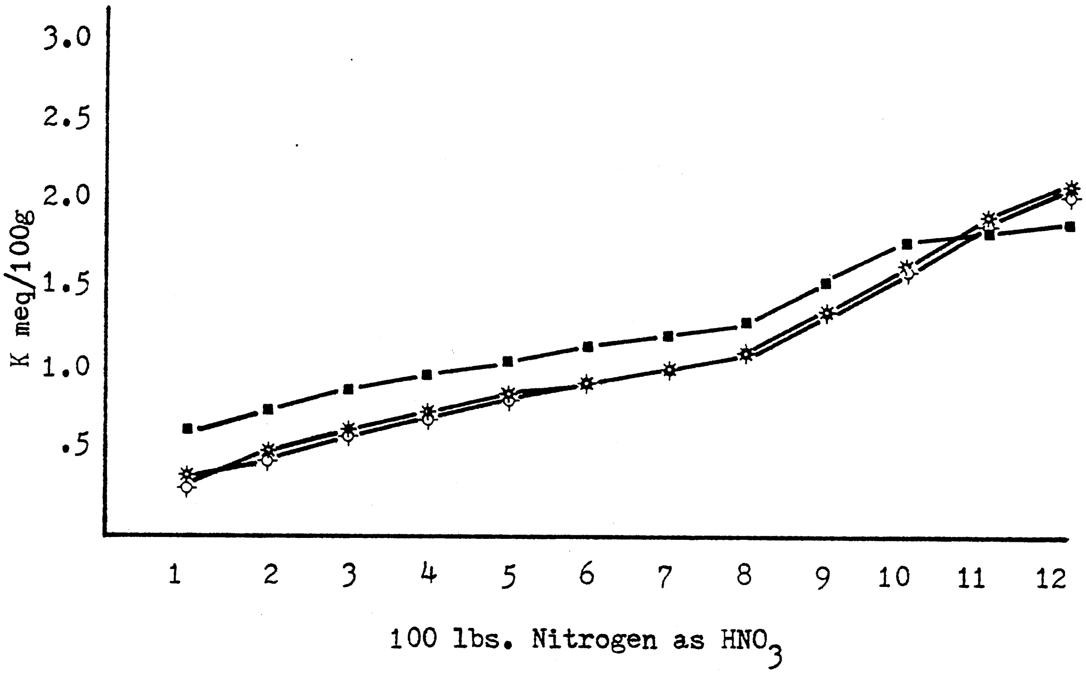

Figure 28. K Removal from Healy Soil by HNO_3 Leaching

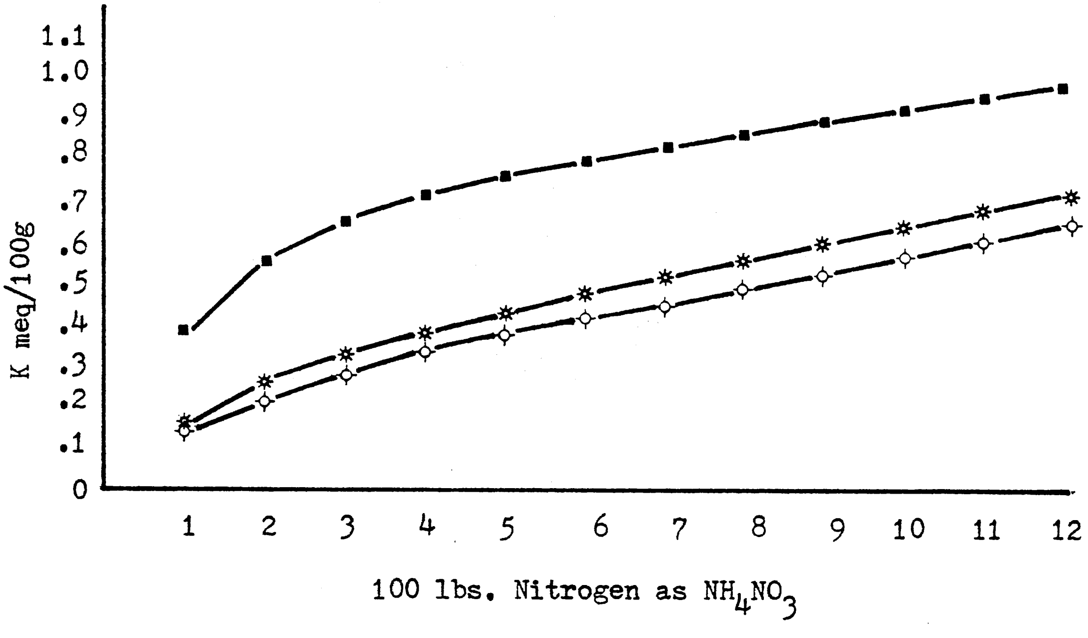

Figure 29. K Removal from Healy Soil by NH_4NO_3 Leaching

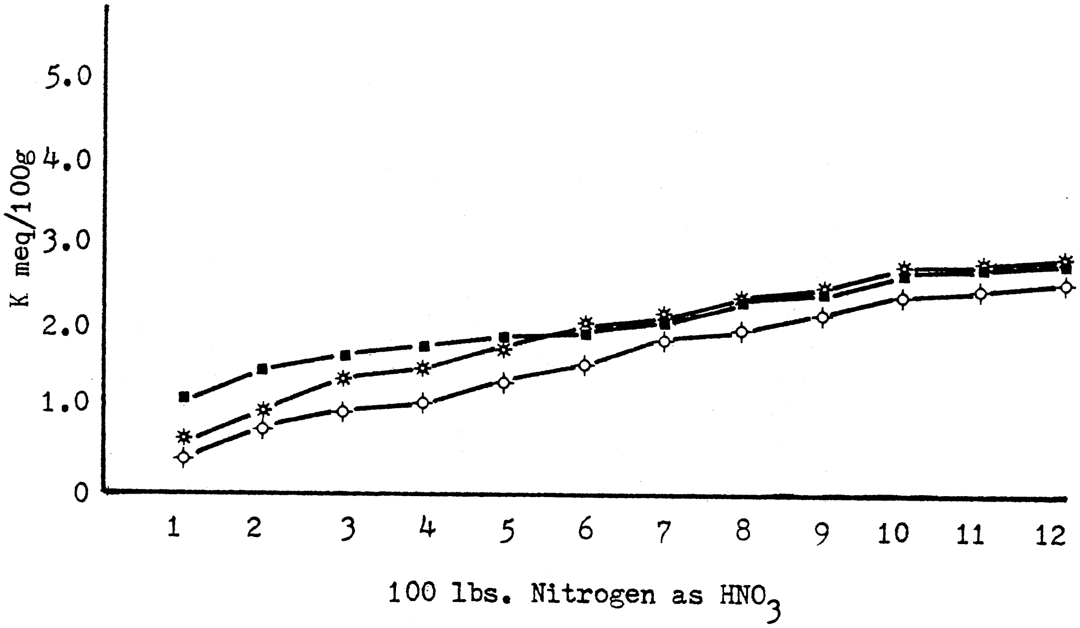

Figure 30. K Removal from Virgin Soil by HNO_3 Leaching

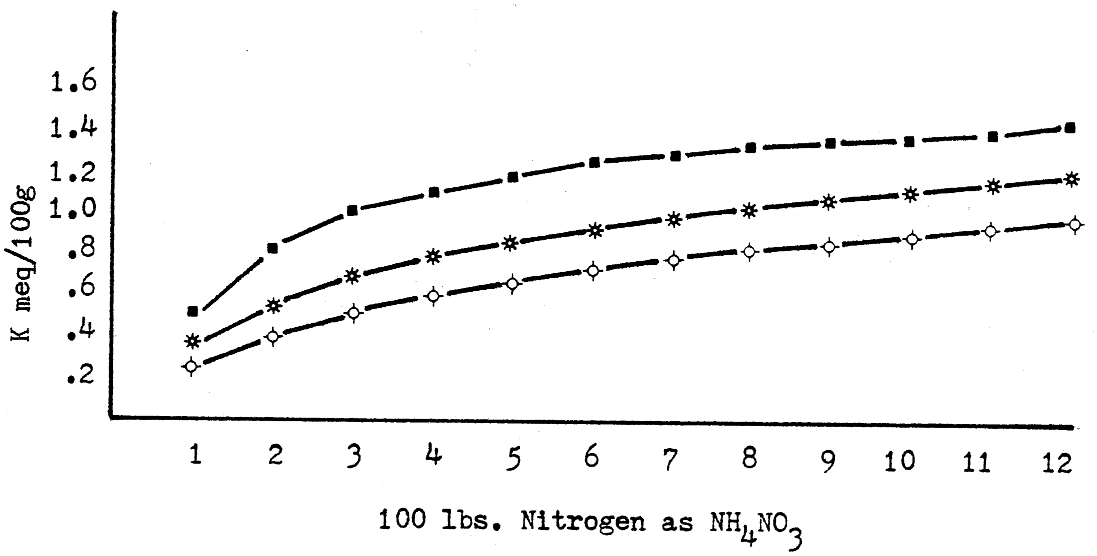

Figure 31. K Removal from Virgin Soil by NH_4NO_3 Leaching

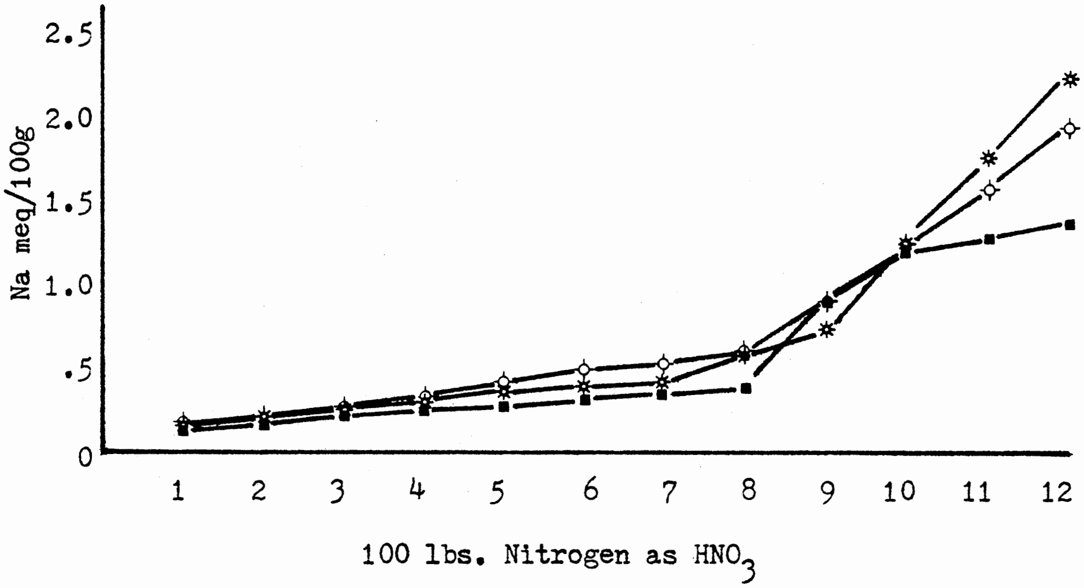

Figure 32. Na Removal from Healy Soil by HNO_3 Leaching

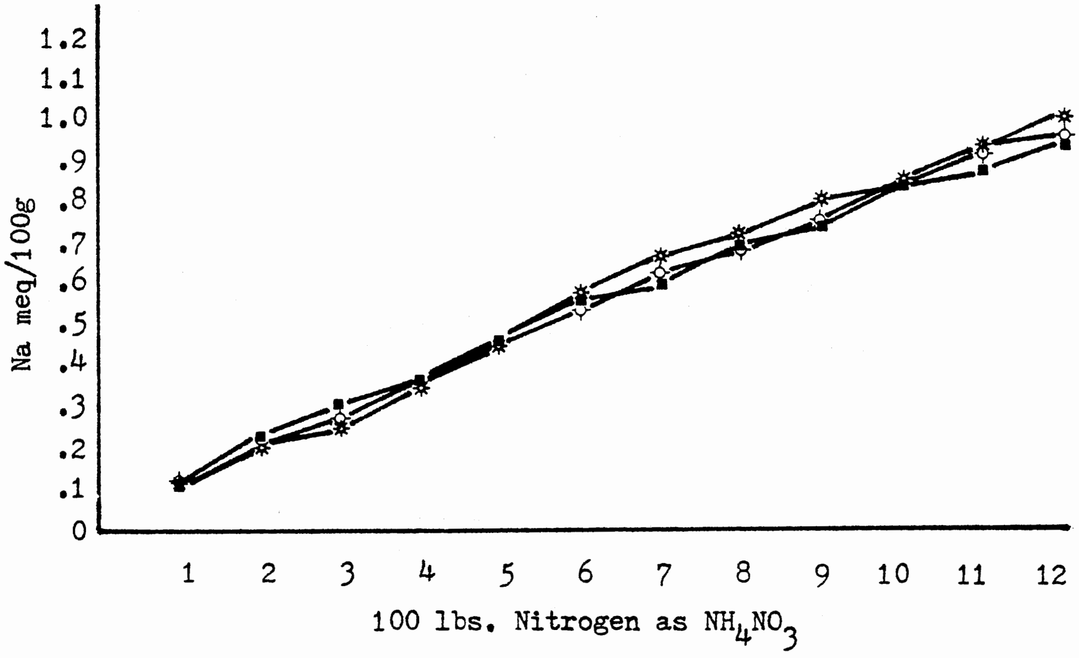

Figure 33. Na Removal from Healy Soil by NH_4NO_3 Leaching

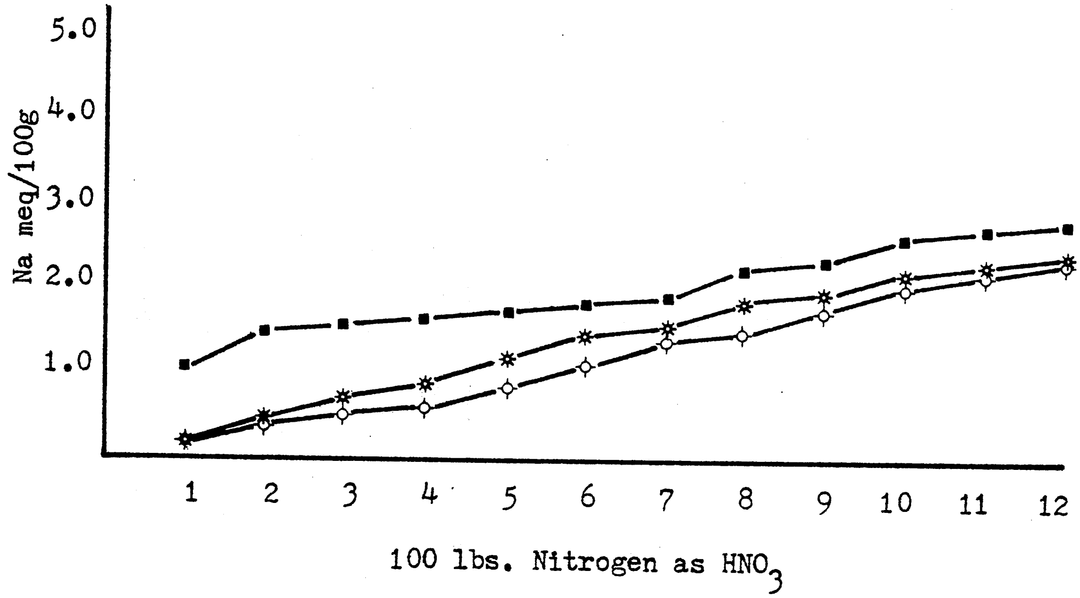

Figure 34. Na Removal from Virgin Soil by HNO_3 Leaching

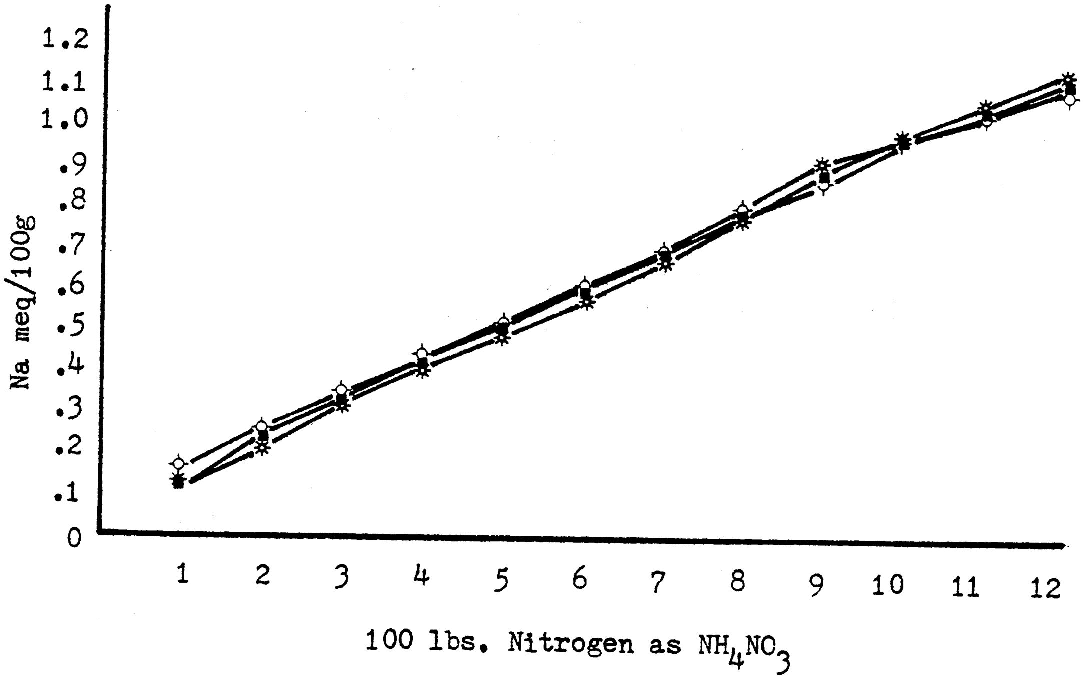

Figure 35. Na Removal from Virgin Soil by NH_4NO_3 Leaching

TABLE XVI

CORRELATION COEFFICIENT AND STRAIGHT LINE EQUATION FOR HNO_3 AND NH_4NO_3 REMOVAL OF BASIC SOIL CONSTITUENTS

Depth	Correlation Coefficient	Equation to Fit Straight Line to Data Points ($y=b+mx$)
HNO_3 Removal of Al		
Healy		
0-15	.978	$y = 5.97 + .011x$
30-45	.989	$y = 5.37 + .021x$
60-90	.981	$y = 7.83 + .020x$
Virgin		
0-15	.994	$y = -.412 + .012x$
30-45	.993	$y = -.267 + .017x$
60-90	.994	$y = -.690 + .019x$
NH_4NO_3 Removal of Al		
Healy		
0-15	.996	$y = -.003 + .0004x$
30-45	.997	$y = -.158 + .001x$
60-90	.997	$y = -.007 + .0008x$
Virgin		
0-15	.994	$y = -.008 + .0007x$
30-45	.804	$y = -.145 + .001x$
60-90	.984	$y = -.049 + .0006x$
HNO_3 Removal of Ca		
Healy		
0-15	.985	$y = 3.94 + .003x$
30-45	.968	$y = 8.92 + .004x$
60-90	.978	$y = 10.85 + .004x$
Virgin		
0-15	.834	$y = 11.57 + .004x$
30-45	.899	$y = 9.29 + .004x$
60-90	.894	$y = 10.00 + .005x$

TABLE XVI (Continued)

Depth	Correlation Coefficient	Equation to Fit Straight Line to Data Points ($y=b+mx$)
NH_4NO_3 Removal of Ca		
Healy		
0-15	.984	$y = .60 + .002x$
30-45	.980	$y = 1.16 + .003x$
60-90	.979	$y = 1.26 + .003x$
Virgin		
0-15	.991	$y = .78 + .003x$
30-45	.990	$y = .996 + .003x$
60-90	.986	$y = 1.19 + .003x$
HNO_3 Removal of Mg		
Healy		
0-15	.994	$y = 1.09 + .002x$
30-45	.979	$y = 3.42 + .003x$
60-90	.985	$y = 4.74 + .003x$
Virgin		
0-15	.948	$y = 4.14 + .002x$
30-45	.973	$y = 2.88 + .003x$
60-90	.962	$y = 3.93 + .003x$
NH_4NO_3 Removal of Mg		
Healy		
0-15	.991	$y = .23 + .0006x$
30-45	.983	$y = .48 + .001x$
60-90	.978	$y = .63 + .001x$
Virgin		
0-15	.976	$y = .26 + .0007x$
30-45	.976	$y = .47 + .001x$
60-90	.973	$y = .68 + .001x$

TABLE XVI (Continued)

Depth	Correlation Coefficient	Equation to Fit Straight Line to Data Points (y=b+mx)
HNO_3 Removal of K		
Healy		
0-15	.986	y = .50 + .001x
30-45	.976	y = .07 + .002x
60-90	.971	y = .13 + .002x
Virgin		
0-15	.986	y = 1.19 + .002x
30-45	.981	y = .74 + .002x
60-90	.992	y = .41 + .002x
NH_4NO_3 Removal of K		
Healy		
0-15	.943	y = .48 + .0005x
30-45	.988	y = .18 + .0005x
60-90	.990	y = .15 + .0004x
Virgin		
0-15	.915	y = .77 + .0007x
30-45	.959	y = .47 + .0007x
60-90	.968	y = .32 + .0006x
HNO_3 Removal of Na		
Healy		
0-15	.912	y = -.21 + .001x
30-45	.855	y = -.35 + .002x
60-90	.915	y = -.24 + .002x
Virgin		
0-15	.982	y = 1.07 + .002x
30-45	.994	y = .05 + .002x
60-90	.995	y = -.14 + .002x

TABLE XVI (Continued)

Depth	Correlation Coefficient	Equation to Fit Straight Line to Data Points ($y=b+mx$)
NH_4NO_3 Removal of Na		
Healy		
0-15	.997	$y = .09 + .0007x$
30-45	.995	$y = .04 + .0008x$
60-90	.998	$y = .05 + .0008x$
Virgin		
0-15	.997	$y = .06 + .0009x$
30-45	.999	$y = .03 + .0010x$
60-90	.999	$y = .09 + .0009x$

y = meq/100g cation concentrations removed by HNO_3 or NH_4NO_3 treatments

x = 100 lbs. increments of nitrogen applied as HNO_3 or NH_4NO_3

compared to the removal of Al with NH_4NO_3 (Figures 16, 17). The highest Al amount removed was in the 60-90 cm sample while lowest occurred in the 0-15 sample. Al removal by nitric acid and NH_4NO_3 leaching from the Virgin soil indicated a nineteen and fourteen fold increase in Al removed in the initial and final leaching stages respectively (Figures 18, 19). Al removal with nitric acid leaching increased with depth into the profile while NH_4NO_3 leaching removal of Al was higher in the 30-45 cm sample, and lower in the surface soil sample (0-15 cm), and considerably less in the lower depth sample (60-90 cm).

The first leaching and the last of the leaching process resulted in a nine and three fold increase in the nitric acid leaching over the NH_4NO_3 leaching respectively for the removal of calcium from the Healy soil (Figures 20, 21). The lower horizons act as an acid sink and the removal of cations from the surface horizons could account for the maximum subsurface and minimum surface removal of calcium from the Healy soil by both treatments. The Virgin, acid treated soil, produced a nine fold increase in calcium removal, when compared to the NH_4NO_3 treatment (Figures 22, 23). The near neutral pH values of the Virgin soil profile reflects the maximum acid removal of calcium occurring in the surface horizons and minimal removal directly below the surface horizon and intermediate removal confined to the lower depths. The NH_4NO_3 leached Virgin soil showed an accelerated removal of calcium with depth.

The initial eight fold increase and the four fold increase at the end of the leaching process reflects the effectiveness of acid over NH_4NO_3 removal of magnesium from the Healy soil (**Figures** 24, 25). The acid and NH_4NO_3 treated Healy soil produced a progressive depletion of magnesium with depth. The acid treated Virgin soil showed an eight fold increase initially and a four fold increase in removal of magnesium over the NH_4NO_3 leached samples (Figures 26, 27). Unlike the acid treated Healy soil, the Virgin surface soil showed an intermediate removal of magnesium and the depths at 15-30 and 30-45 cm had the lowest removal, while maximum magnesium removal occurred at the lower depths (45-60 and 60-90 cm). The NH_4NO_3 leached Virgin soil showed magnesium removal to be similiar to the acid and NH_4NO_3 leached Healy soil.

The acid and NH_4NO_3 leached Healy soil showed a two to three fold increase in potassium removal between the beginning and ending leaching (Figures 28, 29). The acid leaching showed the highest potassium removal in 30-45 and 60-90 cm horizons, while the lowest removal occurred in the 15-30 cm horizon with intermediate removal in the 45-60 and 0-15 cm horizons. Potassium removal by NH_4NO_3 leachings was progressively lower with increase in soil depth. The acid and NH_4NO_3 leachings showed potassium removal from the Virgin soil to increase two fold at the beginning and ending of the leaching treatment (Figures 30, 31). The highest acid leaching potassium removal occurred in the 30-45 cm depth, followed closely by the 0-15 cm surface sample, with comparable removal in 15-30, 60-90 cm depths, and intermediate removal at the 45-60 cm horizon of the Virgin soil. Potassium removal by NH_4NO_3 leachings declined gradually with depth.

The removal of sodium by acid and NH_4NO_3 leaching of the Healy soil showed the smallest differences between surface and subsurface horizons of all elements studied (Figures 32, 33). Removal of sodium by acid leaching was constant with each leaching until the eight hundred pound was added and then a rapid increase occurred. Removal of sodium was minimized by acid leaching in the 0-15, 15-30 depths, and maximized in the 30-45, 60-90 cm depths. NH_4NO_3 leaching removal of sodium was the highest in the 45-60 cm sample, lowest in the 0-15 cm sample, with identical amounts removed at the remaining depths. The acid and NH_4NO_3 leachings removal of sodium was two to three fold higher between the beginning and ending leaching in Virgin soil (Figures 34, 35). The highest acid removal of sodium in the Virgin soil occurred in the 0-15, and 45-60 cm horizons, with intermediate removal at 30-45 and 60-90 cm depths, and the lowest removal of sodium occurred at the 15-30 cm depth. Both the Virgin and Healy soil profiles showed comparable removal of sodium.

CHAPTER V

SUMMARY AND CONCLUSION

X-ray diffraction, sodium citrate extraction, surface area, and cation exchange capacity evaluation substantiates the existence of amorphous material in the Carrier, Healy, and Virgin soils. Interlayer Al as an atoll development occurs in clays of the surface and subsurface in the Lahoma soil. The presence of interlayer Al in the Lahoma soil clays differs from the generally accepted concept of interlayer development in the surface and non-subsurface soil clays as suggested by Brown (1953), Glenn (1960) and Nash (1963). The effect of organic matter, pH, and other factors of weathering may induce breakdown of primary soil minerals and placement in the subsurface of "template" clays for interlayer development. This hypothesis may explain the findings of this study. The presence of and the complexing ability of the organic matter could minimize interlayer development by reducing the ion product $(Al)(OH)_3 \cdot H_2O$ concentration as reported by Clark and Nichol (1966) occurring in high over low organic matter soils. The acidic pH found in the soils investigated in this study compare with the findings of Glenn and Nash (1964) which suggest an optimum pH of about 4.5 for Al interlayer development. Fluctuations in the optimum pH range for interlayer development could reflect clay mineral involvement in the Lahoma soil. Rich (1968) suggested an optimum interlayer development in vermiculite around a pH of 4.5 to 5.0, while a pH of 5.0 to 6.0 would be optimum for montmorillonite. X-ray diffraction analysis and pH data verifies the presence of vermiculite associated with the lower pH, while both vermiculite and montmorillonite appear together at the higher pH. Also, the type of Al could be related to the soil pH, with Al^{+3} forms dominating the acidic range associated with the surface depths of the Carrier and Lahoma soil, while $Al(OH)_3$ exists near a neutral pH range associated with subsurface depths of the Carrier and especially the Lahoma soils. Finally, the influence of weathering on soils as reflected in the wetting and drying cycles could account for the surface and subsurface soil development encountered in this study, especially when lower organic matter levels favors subsurface development as suggested by Rich (1968). According to Mitchel et al. (1964), a clay mineralogy study of glacial till soil profiles showed the presence of an iron-Al interlayer material at a depth of 140 cm which is considerably deeper than the horizons studied in this report.

The erratic values of the high surface area and cation exchange capacity values from the illite-kaolinite clay mineralogy of the Carrier, Healy, and Virgin soils can be explained by the presence and reactive nature of the amorphous hydrous oxides of Al and organic matter-cation complexes. Fieldes et al. (1952) attributed the higher than expected cation exchange capacity values not to the presence of organic matter but to the principal exchange material, amorphous hydrous oxides of Al. Kelley and Page (1942) believed the high cation exchange capacity properties of Hawaiian soils could be attributed to the presence of amorphous material. The extensive literature review by Mitchell et al. (1964) attributed high cation exchange capacity values and higher total surface area measured by organic molecule treatment, such as ethylene glycol and glycerol, to the presence and retentive power of the amorphous material. The expandable clay mineralogy of the Lahoma soil would encourage interlayer formation and the presence of amorphous material, which could influence the cation exchange capacity and surface area data. Clark and Nichol (1966) concluded that the high cation exchange capacity values reported by McLean et al. (1964) could be related to the liberation of exchange sites following acid removal of Al and iron blockage material. Clark (1964) attributed the cation exchange capacity values to increasing dissociation of acid functional groups associated with organic matter and exchange site liberation by removal of Al and iron blockage material. Clark (1964) and Paver and Marshall (1934) reported drastically reduced cation exchange capacity by Al retention and interlayer formation on expansible layer silicates. Tamura (1957) encountered reduced or nonexisting organic molecule swelling when the interlayer material was present, but removal of the interlayer encouraged swelling. Tamura's findings were somewhat similar to the organic molecule treatment responses of the fine and coarse clay fractions reported in this study.

The atoll or island arrangement of the interlayer material is substantiated by the multiple heat treatment findings on the potassium saturated clays and the sodium citrate extractable Al from the fine and coarse soil clays. The presence of sodium citrate extractable Al in the Carrier, Healy, and Virgin soils with no detectable Al interlayer formation can be explained by the ability of sodium citrate to attack and chelate amorphous forms of Al according to Mitchell et al. (1964). Also, the amount and stability of the interlayer Al influences the degree of attack and solublize by the sodium citrate treatments. Rapid digestion and removal of Al in the Lahoma soil clays would support quantitatively small, unstable interlayer development similar to the proposed atoll or island arrangement. According to Barnhisel (1977), the atoll structure results in insufficient numbers of props blocking the exchange sites which cannot support the 14 A° spacing when potassium saturated and when heated at elevated temperatures, resulting in structural collapsing to approximately 10 A°. Similar collapsing results occurred in the subsurface Lahoma soil clays.

Relationships between various soil chemical properties were investigated with good correlation existing between surface area and cation exchange capacity for the non-sodium citrate treated Healy and Virgin fine clay fractions ($r = .706$), while the correlations were weak to poor for the remaining fine and coarse soil clay fractions. Excellent relationships were found between surface area and interlayer Al for the Carrier sodium citrate treated fine clay ($r = .903$), followed by the non-sodium citrate treated Lahoma ($r = .870$) and the Carrier ($r = .796$) fine clay fractions. Poor to nonexisting surface area to interlayer Al relationships were found in the remaining fine and coarse soil clay fractions. Poor cation exchange capacity and interlayer Al relationships were found for all soil clay fractions except the sodium citrate treated Lahoma fine ($r = .813$) and Healy fine ($r = .708$) and the Virgin coarse ($r = .855$) clay fractions.

Excellent correlations were found between percent clay and cation exchange capacity for all soils ($r = .815$ to $.987$), soil-water pH and soil-salt pH of the Carrier ($r = .992$) and Lahoma ($r = .997$) soils, and Lahoma soil-water pH and water soluble Al ($r = .991$). The remaining relationships tested involving percent organic matter and cation exchange capacity, exchangeable Al and water soluble Al, soil-salt pH and exchangeable Al indicated poor to non-significant relationships. Correlations involving surface area, percent organic matter, cation exchange capacity, interlayer Al, both water soluble and exchangeable Al reflect the reactive nature and presence of interlayer, amorphous Al complexes and organic matter.

In conclusion, agricultural manipulation by man involving acid forming fertilizer applications with an uncontrolled pH state has generated an undesirable acidic soil environment which encourages the following: (1) cation removal from active soil surfaces with eventual deposition in subsurface depths in which availability to the plant is limited to deep rooting species, (2) nature's gradual development of an acidic state has been accelerated by man's manipulation aided by fertilizer use resulting in toxic Al levels in the surface depths and creation in the subsurface of interlayer Al atoll formations of the clay minerals, (3) reversible chemical weathering and mineral transformation from the reactive expansible silicate clay minerals, such as montmorillonite and vermiculite, to the less reactive and less expansible ones, such as hydrous mica (illite) and kaolinite, with amorphous and interlayer complexed clay minerals acting as intermediates.

Through careful management practices, the undesirable affects associated with increasing acidity can be substantially reduced or controlled. The use of lime will increase pH, reduce Al solubility in the surface soil and by calcium deposition in the subsurface through the illuviation-eluviation process, increase the concentration of calcium ions in the surface soil, and generally, improve ion availability while reducing the toxic affects of excess Al and manganese. Improvement of soil organic matter levels is needed by striking a balance between maintaining and improving existing management practices for maintenance of soil organic matter. Finally, the farmer's realization that maximum yields through fertilizer use is a desirable goal when coupled with a common sense approach in solving todays problems and production quotes, while maintaining an outlook on future problems and production.

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APPENDIX

A Typical Soil Profile of the Carrier Location

A typical profile of the Pond Creek silt loam having a zero to one percent slope and representing the Carrier location has been summarized:

Ap-- 0 to 6 inches, dark-brown (7.5YR 4/4) silt loam, dark brown (7.5YR 3/2) when moist; weak, fine, granular structure; friable when moist, slightly hard when dry; slightly acid, pH 6.5; gradual boundary.

A12--6 to 12 inches, dark-brown (7.5YR 4/4) silt loam, dark brown (7.5YR 3/2) when moist; moderate, medium, granular structure; friable when moist, slightly hard when dry; neutral, pH 7.0; gradual boundary.

B1---12 to 22 inches, reddish-brown (5YR 4/3) silty clay loam, dark reddish brown (5YR 3/3) when moist; strong, coarse, granular structure to weak, fine, subangular blocky structure; neutral pH 7.0; gradual boundary.

B2t--22 to 30 inches, reddish-brown (5YR 4/3) silty clay loam, dark reddish brown (5YR 3/3) when moist, moderate, fine, subangular blocky structure; firm when moist, hard when dry; neutral, pH 7.0; patchy clay films; gradual boundary.

B3---30 to 46 inches, reddish-brown (5YR 4/3) heavy silty clay loam or light clay, dark reddish brown (5YR 3/3) when moist; strong, medium, subangular blocky structure; firm when moist, hard when dry; neutral, pH 7.0; gradual boundary.

C---46 to 68 inches, reddish-brown (5YR 4/4) silty clay loam, dark reddish brown (5YR 3/4) when moist; massive; calcareous; few small concretions of calcium carbonate.

The A horizon ranges from 12 to 16 inches in thickness and from dark brown to very dark grayish brown in hue. The depth to calcareous material ranges from 4 to 6 feet. The color of the C horizon ranges from reddish brown to yellowish red.

A Typical Soil Profile of the Lahoma Location

A typical profile of the Meno loamy fine sand having a zero to three percent slope and representing the Lahoma location has been summarized:

A11--0 to 10 inches, brown (10YR 5/3) loamy fine sand, dark brown (10YR 3/3) when moist; weak, medium, granular structure; soft when dry, very friable when moist; pH 5.6; gradual boundary.

A12--10 to 24 inches, brown (7.5YR 5/4) loamy fine sand, dark brown (7.5YR 4/3) when moist; weak, medium, granular structure; soft when dry, very friable when moist, pH 6.0; clear boundary.

B21t--24 to 34 inches, brown (7.5YR 5/4) light sandy clay loam, dark brown (7.5YR 4/4) when moist; faintly mottled with grayish brown and strong brown; weak, medium, granular structure; pH 6.0; gradual boundary.

B22t--34 to 44 inches, mottled brown (7.5YR 5/4), strong-brown (7.5YR 5/6), and gray (10YR 6/1) sandy clay loam; weak, medium, subangular blocky structure; hard when dry, friable when moist; pH 6.0; diffuse boundary.

C--44 to 60 inches +, mottled strong-brown (7.5YR 5/6) and grayish-brown (10YR 5/2) fine sandy loam; massive (structureless); pH 6.0

The A horizon ranges from dark brown to light brownish gray. The A12 horizon is faintly mottled in the lower lying areas. The Bt horizons range from sandy clay loam to heavy fine sandy loam that has a content of clay of about 17 to 20 percent. Depth to a horizon containing distinct mottles ranges from 20 to 30 inches. The mottles in the lower part of the B22t horizon range from distinct to prominent and are more yellowish and grayish than the soil mass. The horizons below the Bt horizons are stratified in some places. The strata range from loamy fine sand to sandy clay loam. Below a depth of 48 inches, there is an occasional layer of dark-colored heavy sandy clay loam to clay loam. Reaction of the A horizons is medium acid to neutral. In places free carbonates occur below a depth of 60 inches.

TABLE XVII

ANALYSIS OF VARIANCE FOR CHEMICAL PROPERTIES OF CARRIER AND LAHOMA SOILS

Source	Degrees of Freedom	Means Squares								
		KCl Al	H_2O Al	H_2O Ca	H_2O Mg	H_2O Na	H_2O K	pH H_2O	pH KCl	% Clay
LOC	1	.9831	.5535	.0001	.0147	.1809	.0080	1.9404	9.8568	6974.9860
QUAD (LOC)	6	.1494	.0533	.0132	.0082	.0765	.0015	2.0704	1.6769	396.9845
HOLE (LOC QUAD)	32	.0191	.0236	.0041	.0012	.0099	.0006	.2642	.2058	25.4083
DEPTH	4	1.9901	.0335	.0221	.0011	.0040	.0141	34.3145	25.1183	1700.6881
LOC*DEPTH	4	.4154	.0341	.0063	.0015	.0009	.0055	1.1643	1.9851	344.4176
QUAD*DEPTH (LOC)	24	.0568	.0070	.0023	.0009	.0044	.0001	.1804	.2070	26.3437
HOLE*DEPTH (LOC QUAD)	128	.0146	.0088	.0024	.0005	.0049	.0002	.0626	.0831	10.0688
CORRECTED TOTAL	199	.0771	.0160	.0035	.0012	.0086	.0007	.8898	.7564	101.8665

TABLE XVIII

ANALYSIS OF VARIANCE FOR CHEMICAL PROPERTIES OF CARRIER AND LAHOMA SOILS

Source	Degrees of Freedom	Mean Squares					
		NH_4 Ca	NH_4 Mg	NH_4 Na	NH_4 K	% O.M.	CEC
LOC	1	3.1700	1.3213	.9096	.0234	.4470	.2880
QUAD (LOC)	2	1.7238	12.4782	1.3144	.0217	.6067	46.9220
DEPTH	4	41.3398	10.3756	.4393	.0438	.2320	79.6742
LOC*DEPTH	4	2.5933	.0920	.2859	.0073	.0493	4.5942
QUAD*DEPTH (LOC)	8	1.7284	.7589	.3577	.0058	.0303	6.1707
CORRECTED TOTAL	19	10.3251	3.9063	.4895	.0167	.1594	25.2932

TABLE XIX

CHEMICAL ANALYSIS DATA ON CARRIER SOIL

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
CAR	1	1	15	0.577778	0.0111111	0.16875	0.104167	0.516304
CAR	1	1	30	0.022222	0.0222222	0.21875	0.114583	0.353261
CAR	1	1	45	0.011111	0.0000000	0.16875	0.093750	0.309783
CAR	1	1	60	0.011111	0.0000000	0.14375	0.083333	0.315217
CAR	1	1	90	0.011111	0.0000000	0.14375	0.093750	0.250000
CAR	1	2	15	0.766667	0.0000000	0.05000	0.031250	0.222826
CAR	1	2	30	0.077778	0.0000000	0.08750	0.041667	0.266304
CAR	1	2	45	0.066667	0.0222222	0.26875	0.135417	0.358696
CAR	1	2	60	0.066667	0.0000000	0.16875	0.093750	0.336957
CAR	1	2	90	0.022222	0.0000000	0.14375	0.093750	0.331522
CAR	1	3	15	0.377778	0.0000000	0.11250	0.052083	0.288043
CAR	1	3	30	0.055556	0.0000000	0.13750	0.072917	0.211957
CAR	1	3	45	0.044444	0.0000000	0.18750	0.083333	0.358696
CAR	1	3	60	0.022222	0.0000000	0.23125	0.145833	0.309783
CAR	1	3	90	0.011111	0.0000000	0.16250	0.104167	0.326087
CAR	1	4	15	0.444444	0.0000000	0.06250	0.031250	0.298913
CAR	1	4	30	0.055556	0.0000000	0.10625	0.052083	0.255435
CAR	1	4	45	0.066667	0.0111111	0.15000	0.072917	0.255435
CAR	1	4	60	0.033333	0.0111111	0.10625	0.062500	0.309783
CAR	1	4	90	0.011111	0.0111111	0.12500	0.072917	0.293478
CAR	1	5	15	0.422222	0.0111111	0.06875	0.031250	0.326087
CAR	1	5	30	0.033333	0.0222222	0.11250	0.062500	0.255435
CAR	1	5	45	0.022222	0.0222222	0.10625	0.062500	0.320652
CAR	1	5	60	0.011111	0.0222222	0.10000	0.062500	0.239130
CAR	1	5	90	0.011111	0.0222222	0.12500	0.083333	0.402174

TABLE XIX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_H2CK	PHH2O	PHKCL	PCTCLAY
CAR	1	1	15	0.096154	4.6	3.8	12.6
CAR	1	1	30	0.048077	5.6	5.3	18.6
CAR	1	1	45	0.022436	6.4	5.6	23.6
CAR	1	1	60	0.022436	6.9	5.9	24.6
CAR	1	1	90	0.022436	6.9	6.0	36.6
CAR	1	2	15	0.064103	4.5	3.8	9.6
CAR	1	2	30	0.041667	5.4	4.6	11.6
CAR	1	2	45	0.035256	6.4	5.8	22.6
CAR	1	2	60	0.025641	7.0	6.0	31.6
CAR	1	2	90	0.025641	6.8	6.0	40.6
CAR	1	3	15	0.176282	4.6	4.0	12.6
CAR	1	3	30	0.038462	5.8	5.3	12.6
CAR	1	3	45	0.025641	6.6	5.9	13.6
CAR	1	3	60	0.028846	6.9	6.1	31.6
CAR	1	3	90	0.025641	6.8	6.0	45.6
CAR	1	4	15	0.080128	4.7	4.1	15.8
CAR	1	4	30	0.044872	5.1	4.7	15.8
CAR	1	4	45	0.028846	6.0	5.6	18.8
CAR	1	4	60	0.025641	6.4	5.7	21.8
CAR	1	4	90	0.028846	6.4	5.9	34.6
CAR	1	5	15	0.057692	4.7	3.9	13.6
CAR	1	5	30	0.060897	5.9	5.5	13.6
CAR	1	5	45	0.022436	6.4	5.9	27.6
CAR	1	5	60	0.022436	6.5	6.0	36.6
CAR	1	5	90	0.028846	6.5	6.0	45.6

TABLE XIX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
CAR	2	1	15	0.577778	0.0111111	0.05625	0.020833	0.239130
CAR	2	1	30	0.055556	0.0111111	0.14375	0.072917	0.309783
CAR	2	1	45	0.044444	0.0111111	0.11875	0.062500	0.217391
CAR	2	1	60	0.033333	0.0222222	0.15000	0.104167	0.239130
CAR	2	1	90	0.066667	0.0222222	0.16250	0.114583	0.277174
CAR	2	2	15	0.888889	0.0222222	0.09375	0.041667	0.331522
CAR	2	2	30	0.088889	0.0222222	0.09375	0.041667	0.271739
CAR	2	2	45	0.066667	0.0222222	0.16250	0.104167	0.288043
CAR	2	2	60	0.055556	0.0222222	0.15625	0.093750	0.320652
CAR	2	2	90	0.044444	0.0111111	0.15000	0.093750	0.309783
CAR	2	3	15	0.355556	0.0222222	0.06250	0.031250	0.217391
CAR	2	3	30	0.111111	0.0111111	0.12500	0.062500	0.336957
CAR	2	3	45	0.077778	0.0111111	0.12500	0.072917	0.293478
CAR	2	3	60	0.055556	0.0111111	0.13750	0.083333	0.320652
CAR	2	3	90	0.044444	0.0111111	0.13125	0.093750	0.255435
CAR	2	4	15	0.544444	0.0111111	0.06875	0.031250	0.222826
CAR	2	4	30	0.066667	0.0111111	0.12500	0.062500	0.239130
CAR	2	4	45	0.044444	0.0111111	0.13125	0.083333	0.315217
CAR	2	4	60	0.055556	0.0111111	0.16250	0.093750	0.309783
CAR	2	4	90	0.044444	0.0111111	0.12500	0.072917	0.331522
CAR	2	5	15	0.544444	0.0111111	0.06875	0.031250	0.266304
CAR	2	5	30	0.033333	0.0111111	0.11250	0.052083	0.173913
CAR	2	5	45	0.044444	0.0111111	0.14375	0.072917	0.277174
CAR	2	5	60	0.044444	0.0222222	0.14375	0.072917	0.293478
CAR	2	5	90	0.033333	0.0111111	0.11250	0.062500	0.271739

TABLE XIX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_H2OK	PHH2O	PHKCL	PCTCLAY
CAR	2	1	15	0.083333	4.5	4.0	12.6
CAR	2	1	30	0.060897	5.4	5.0	14.6
CAR	2	1	45	0.022436	6.3	5.8	22.6
CAR	2	1	60	0.025641	6.6	6.1	29.6
CAR	2	1	90	0.032051	6.7	6.1	46.6
CAR	2	2	15	0.169872	4.4	3.8	13.6
CAR	2	2	30	0.073718	5.0	4.6	15.6
CAR	2	2	45	0.035256	6.5	5.8	27.6
CAR	2	2	60	0.028846	6.5	6.0	21.6
CAR	2	2	90	0.025641	6.7	6.0	44.6
CAR	2	3	15	0.064103	4.5	4.0	13.6
CAR	2	3	30	0.041667	5.5	5.1	11.6
CAR	2	3	45	0.038462	5.7	5.1	19.6
CAR	2	3	60	0.025641	6.3	5.7	28.6
CAR	2	3	90	0.025641	6.4	5.9	42.6
CAR	2	4	15	0.118590	4.7	3.8	15.6
CAR	2	4	30	0.064103	5.8	4.9	17.6
CAR	2	4	45	0.035256	6.4	5.3	24.6
CAR	2	4	60	0.032051	7.0	5.8	26.6
CAR	2	4	90	0.022436	7.4	6.0	29.6
CAR	2	5	15	0.115385	4.8	3.7	15.6
CAR	2	5	30	0.070513	5.6	4.8	19.6
CAR	2	5	45	0.028846	6.1	5.6	21.6
CAR	2	5	60	0.022436	7.0	5.9	21.6
CAR	2	5	90	0.022436	7.3	6.0	29.6

TABLE XIX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
CAR	3	1	15	0.544444	0.0111111	0.10000	0.0520833	0.304348
CAR	3	1	30	0.044444	0.0111111	0.14375	0.0729167	0.228261
CAR	3	1	45	0.044444	0.0111111	0.11250	0.0625000	0.228261
CAR	3	1	60	0.044444	0.0111111	0.14375	0.0833333	0.309783
CAR	3	1	90	0.033333	0.0111111	0.11875	0.0729167	0.255435
CAR	3	2	15	0.344444	0.0111111	0.06875	0.0312500	0.293478
CAR	3	2	30	0.044444	0.0000000	0.10625	0.0625000	0.320652
CAR	3	2	45	0.033333	0.0111111	0.10625	0.0729167	0.304348
CAR	3	2	60	0.033333	0.0111111	0.11875	0.0833333	0.271739
CAR	3	2	90	0.044444	0.0111111	0.08750	0.0625000	0.298913
CAR	3	3	15	0.533333	0.0111111	0.06875	0.0312500	0.239130
CAR	3	3	30	0.022222	0.0111111	0.10625	0.0520833	0.326087
CAR	3	3	45	0.044444	0.0111111	0.10000	0.0520833	0.309783
CAR	3	3	60	0.033333	0.0111111	0.11250	0.0729167	0.336957
CAR	3	3	90	0.033333	0.0111111	0.11250	0.0729167	0.239130
CAR	3	4	15	0.377778	0.0111111	0.06250	0.0312500	0.298913
CAR	3	4	30	0.055556	0.0111111	0.08750	0.0416667	0.277174
CAR	3	4	45	0.044444	0.0111111	0.15625	0.0833333	0.228261
CAR	3	4	60	0.033333	0.0111111	0.13125	0.0729167	0.244565
CAR	3	4	90	0.033333	0.0111111	0.11875	0.0729167	0.233696
CAR	3	5	15	0.355556	0.0333333	0.06250	0.0312500	0.217391
CAR	3	5	30	0.033333	0.0333333	0.13125	0.0729167	0.440217
CAR	3	5	45	0.033333	0.0222222	0.18750	0.0833333	0.320652
CAR	3	5	60	0.033333	0.0333333	0.11250	0.0729167	0.347826
CAR	3	5	90	0.022222	0.0444444	0.08750	0.0520833	0.353261

TABLE XIX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_H2CK	PHH2O	PHKCL	PCTCLAY
CAR	3	1	15	0.125000	4.4	3.7	18.6
CAR	3	1	30	0.076923	5.4	4.7	21.6
CAR	3	1	45	0.048077	5.9	5.0	19.6
CAR	3	1	60	0.035256	6.4	5.3	27.6
CAR	3	1	90	0.025641	6.8	5.5	33.6
CAR	3	2	15	0.063333	4.8	3.8	20.6
CAR	3	2	30	0.032051	5.8	4.9	21.6
CAR	3	2	45	0.019231	6.7	5.6	27.6
CAR	3	2	60	0.016026	6.8	5.7	29.6
CAR	3	2	90	0.019231	7.3	5.8	34.6
CAR	3	3	15	0.092949	4.7	3.8	19.6
CAR	3	3	30	0.057692	5.2	4.4	21.6
CAR	3	3	45	0.032051	6.2	5.1	20.6
CAR	3	3	60	0.028846	6.6	5.3	25.4
CAR	3	3	90	0.022436	6.8	5.4	30.4
CAR	3	4	15	0.064103	4.8	3.9	17.4
CAR	3	4	30	0.041667	5.7	4.7	19.4
CAR	3	4	45	0.028846	6.3	5.2	25.4
CAR	3	4	60	0.022436	6.9	5.5	30.4
CAR	3	4	90	0.025641	6.9	5.6	32.4
CAR	3	5	15	0.070513	5.0	3.9	17.4
CAR	3	5	30	0.035256	6.3	5.1	19.4
CAR	3	5	45	0.019231	6.5	5.4	23.4
CAR	3	5	60	0.012821	6.8	5.4	27.4
CAR	3	5	90	0.012821	7.2	5.6	35.4

TABLE XIX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
CAR	4	1	15	0.222222	0.0333333	0.05625	0.020833	0.282609
CAR	4	1	30	0.033333	0.0333333	0.06250	0.031250	0.141304
CAR	4	1	45	0.055556	0.0333333	0.08750	0.041667	0.163043
CAR	4	1	60	0.033333	0.0333333	0.11250	0.062500	0.135870
CAR	4	1	90	0.022222	0.0222222	0.08750	0.052083	0.163043
CAR	4	2	15	0.500000	0.0222222	0.07500	0.031250	0.119565
CAR	4	2	30	0.033333	0.0111111	0.09375	0.041667	0.157609
CAR	4	2	45	0.044444	0.0111111	0.11250	0.052083	0.146739
CAR	4	2	60	0.033333	0.0111111	0.08125	0.041667	0.130435
CAR	4	2	90	0.022222	0.0111111	0.16875	0.135417	0.407609
CAR	4	3	15	0.144444	0.0111111	0.06250	0.031250	0.250000
CAR	4	3	30	0.044444	0.0111111	0.10625	0.062500	0.271739
CAR	4	3	45	0.044444	0.0111111	0.10000	0.052083	0.233696
CAR	4	3	60	0.044444	0.0111111	0.06875	0.031250	0.146739
CAR	4	3	90	0.033333	0.0111111	0.07500	0.052083	0.173913
CAR	4	4	15	0.900000	0.0111111	0.06250	0.020833	0.168478
CAR	4	4	30	0.211111	0.0111111	0.11875	0.041667	0.108696
CAR	4	4	45	0.055556	0.0111111	0.13125	0.072917	0.163043
CAR	4	4	60	0.044444	0.0111111	0.10000	0.062500	0.146739
CAR	4	4	90	0.033333	0.0111111	0.13750	0.093750	0.195652
CAR	4	5	15	0.255556	0.0111111	0.06875	0.031250	0.168478
CAR	4	5	30	0.055556	0.0111111	0.07500	0.031250	0.271739
CAR	4	5	45	0.055556	0.0000000	0.08125	0.041667	0.260870
CAR	4	5	60	0.044444	0.0000000	0.08750	0.052083	0.298913
CAR	4	5	90	0.033333	0.0000000	0.08125	0.041667	0.244565

TABLE XIX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_H2CK	PHH2O	PHKCL	PCTCLAY
CAR	4	1	15	0.057692	5.0	4.1	21.4
CAR	4	1	30	0.032051	6.1	6.0	24.4
CAR	4	1	45	0.019231	6.7	5.3	27.4
CAR	4	1	60	0.019231	6.9	5.5	31.4
CAR	4	1	90	0.016026	7.2	5.6	42.4
CAR	4	2	15	0.086538	4.5	3.8	18.4
CAR	4	2	30	0.048077	5.6	4.8	19.4
CAR	4	2	45	0.028846	6.4	5.2	25.4
CAR	4	2	60	0.012821	6.9	5.5	30.4
CAR	4	2	90	0.022436	7.1	5.7	47.4
CAR	4	3	15	0.051282	5.0	4.1	19.4
CAR	4	3	30	0.022436	6.4	5.3	21.4
CAR	4	3	45	0.012821	6.7	5.5	26.6
CAR	4	3	60	0.012821	7.2	5.9	31.6
CAR	4	3	90	0.016026	7.2	5.9	44.6
CAR	4	4	15	0.118590	4.3	3.7	13.6
CAR	4	4	30	0.067308	4.7	4.0	17.6
CAR	4	4	45	0.032051	6.5	5.5	22.6
CAR	4	4	60	0.012821	7.2	5.9	28.6
CAR	4	4	90	0.019231	7.3	6.0	41.6
CAR	4	5	15	0.089744	4.8	4.0	17.6
CAR	4	5	30	0.028846	5.9	4.8	19.6
CAR	4	5	45	0.012821	6.6	5.5	23.6
CAR	4	5	60	0.012821	7.2	5.9	33.6
CAR	4	5	90	0.009615	7.2	5.8	44.6

TABLE XX

CHEMICAL ANALYSIS DATA ON LAHOMA SOIL

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
LAH	1	1	15	0.288889	0.31111	0.08125	0.041667	0.195652
LAH	1	1	30	0.044444	0.45556	0.08125	0.041667	0.184783
LAH	1	1	45	0.044444	0.17778	0.22500	0.104167	0.326087
LAH	1	1	60	0.044444	0.23333	0.18125	0.177083	0.543478
LAH	1	1	90	0.044444	1.26667	0.15000	0.302083	0.652174
LAH	1	2	15	0.555556	0.21111	0.06875	0.052083	0.298913
LAH	1	2	30	0.266667	0.11111	0.06250	0.020833	0.135870
LAH	1	2	45	0.044444	0.30000	0.06875	0.041667	0.184783
LAH	1	2	60	0.022222	0.12222	0.15625	0.125000	0.375000
LAH	1	2	90	0.055556	0.72222	0.13750	0.114583	0.434783
LAH	1	3	15	0.322222	0.06667	0.06875	0.031250	0.277174
LAH	1	3	30	0.333333	0.07778	0.10000	0.052083	0.396739
LAH	1	3	45	0.066667	0.22222	0.13125	0.062500	0.217391
LAH	1	3	60	0.044444	0.31111	0.12500	0.072917	0.201087
LAH	1	3	90	0.055556	0.01111	0.33125	0.156250	0.179348
LAH	1	4	15	0.488889	0.02222	0.08125	0.020833	0.163043
LAH	1	4	30	0.277778	0.07778	0.06875	0.020833	0.179348
LAH	1	4	45	0.044444	0.04444	0.08125	0.020833	0.173913
LAH	1	4	60	0.044444	0.01111	0.12500	0.041667	0.217391
LAH	1	4	90	0.044444	0.01111	0.11250	0.041667	0.179348
LAH	1	5	15	0.522222	0.02222	0.23750	0.145833	0.625000
LAH	1	5	30	0.066667	0.08889	0.08125	0.031250	0.309783
LAH	1	5	45	0.055556	0.02222	0.10625	0.041667	0.293478
LAH	1	5	60	0.044444	0.25556	0.12500	0.062500	0.347826
LAH	1	5	90	0.044444	0.02222	0.27500	0.104167	0.342391

TABLE XX (Continued)

LOC	GLAC	HOLE	DEPTH	ME_H2OK	PHH2O	PHKCL	PCTCLAY
LAH	1	1	15	0.051282	4.9	3.8	13.4
LAH	1	1	30	0.022436	5.7	4.3	17.4
LAH	1	1	45	0.108974	7.4	6.3	23.4
LAH	1	1	60	0.022436	8.2	7.0	25.4
LAH	1	1	90	0.115385	8.5	7.1	27.4
LAH	1	2	15	0.028846	4.8	3.8	9.4
LAH	1	2	30	0.022436	4.9	3.9	9.4
LAH	1	2	45	0.019231	6.4	5.0	17.5
LAH	1	2	60	0.032051	7.7	6.7	17.5
LAH	1	2	90	0.012821	8.2	6.9	19.5
LAH	1	3	15	0.022436	5.2	4.0	13.5
LAH	1	3	30	0.028846	4.9	3.9	17.5
LAH	1	3	45	0.032051	6.4	5.0	21.5
LAH	1	3	60	0.028846	7.0	5.6	17.5
LAH	1	3	90	0.006410	7.9	7.0	23.5
LAH	1	4	15	0.038462	5.0	3.9	9.5
LAH	1	4	30	0.025641	5.1	3.9	15.5
LAH	1	4	45	0.019231	6.0	4.7	17.5
LAH	1	4	60	0.025641	6.5	5.1	25.5
LAH	1	4	90	0.016026	7.1	5.4	17.5
LAH	1	5	15	0.054487	4.7	3.8	13.5
LAH	1	5	30	0.016026	5.5	4.3	17.5
LAH	1	5	45	0.009615	6.5	4.9	19.5
LAH	1	5	60	0.022436	7.0	5.3	29.5
LAH	1	5	90	0.016026	7.8	6.9	27.6

TABLE XX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
LAH	2	1	15	0.744444	0.022222	0.08125	0.0208333	0.152174
LAH	2	1	30	0.633333	0.077778	0.06250	0.0104167	0.173913
LAH	2	1	45	0.066667	0.033333	0.07500	0.0104167	0.157609
LAH	2	1	60	0.044444	0.177778	0.08750	0.0208333	0.195652
LAH	2	1	90	0.044444	0.211111	0.08750	0.0312500	0.146739
LAH	2	2	15	0.633333	0.022222	0.05625	0.0104167	0.168478
LAH	2	2	30	0.322222	0.155556	0.05625	0.0208333	0.157609
LAH	2	2	45	0.044444	0.255556	0.08125	0.0312500	0.353261
LAH	2	2	60	0.044444	0.088889	0.08750	0.0312500	0.288043
LAH	2	2	90	0.044444	0.122222	0.08125	0.0312500	0.288043
LAH	2	3	15	0.411111	0.033333	0.07500	0.0208333	0.309783
LAH	2	3	30	0.677778	0.044444	0.09375	0.0416667	0.342391
LAH	2	3	45	0.111111	0.088889	0.08750	0.0208333	0.206522
LAH	2	3	60	0.066667	0.077778	0.06250	0.0208333	0.163043
LAH	2	3	90	0.055556	0.077778	0.08125	0.0312500	0.250000
LAH	2	4	15	0.522222	0.033333	0.05625	0.0104167	0.195652
LAH	2	4	30	0.322222	0.044444	0.06250	0.0208333	0.233696
LAH	2	4	45	0.100000	0.355556	0.06875	0.0208333	0.179348
LAH	2	4	60	0.055556	0.322222	0.06875	0.0208333	0.239130
LAH	2	4	90	0.066667	0.111111	0.10000	0.0312500	0.445652
LAH	2	5	15	0.433333	0.055556	0.08125	0.0208333	0.364130
LAH	2	5	30	0.722222	0.022222	0.10000	0.0208333	0.364130
LAH	2	5	45	0.288889	0.066667	0.07500	0.0208333	0.336957
LAH	2	5	60	0.066667	0.366667	0.09375	0.0520833	0.353261
LAH	2	5	90	0.088889	0.300000	0.10000	0.0416667	0.358696

TABLE XX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_H2OK	PHH2O	PHKCL	PCTCLAY
LAH	2	1	15	0.0641026	4.7	3.8	5.6
LAH	2	1	30	0.0288462	4.7	3.8	8.6
LAH	2	1	45	0.0224359	5.6	4.3	9.6
LAH	2	1	60	0.0224359	6.2	5.1	10.4
LAH	2	1	90	0.0192308	6.8	5.6	10.4
LAH	2	2	15	0.0448718	4.8	3.8	5.4
LAH	2	2	30	0.0352564	4.8	3.9	9.4
LAH	2	2	45	0.0352564	5.9	4.7	11.4
LAH	2	2	60	0.0192308	6.3	5.0	9.4
LAH	2	2	90	0.0160256	6.6	5.4	10.4
LAH	2	3	15	0.0576923	4.6	3.8	4.4
LAH	2	3	30	0.0416667	4.4	3.7	5.6
LAH	2	3	45	0.0512821	5.0	4.1	9.6
LAH	2	3	60	0.0256410	5.6	4.5	9.6
LAH	2	3	90	0.0192308	6.2	5.0	9.6
LAH	2	4	15	0.0384615	4.7	3.8	3.6
LAH	2	4	30	0.0288462	5.1	3.9	5.6
LAH	2	4	45	0.0352564	5.7	4.5	7.4
LAH	2	4	60	0.0352564	6.0	4.9	7.4
LAH	2	4	90	0.0288462	6.3	5.1	7.4
LAH	2	5	15	0.0897436	4.8	4.0	4.4
LAH	2	5	30	0.0448718	4.7	3.8	7.4
LAH	2	5	45	0.0352564	5.0	3.9	9.4
LAH	2	5	60	0.0416667	5.7	4.7	9.2
LAH	2	5	90	0.0352564	6.2	5.1	11.2

TABLE XX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
LAH	3	1	15	0.411111	0.077778	0.08750	0.020833	0.358696
LAH	3	1	30	0.333333	0.055556	0.10625	0.031250	0.358696
LAH	3	1	45	0.055556	0.044444	0.17500	0.062500	0.423913
LAH	3	1	60	0.055556	0.066667	0.13125	0.052083	0.380435
LAH	3	1	90	0.111111	0.066667	0.12500	0.052083	0.358696
LAH	3	2	15	0.522222	0.033333	0.09375	0.031250	0.375000
LAH	3	2	30	0.411111	0.033333	0.11875	0.031250	0.418478
LAH	3	2	45	0.111111	0.055556	0.15000	0.062500	0.375000
LAH	3	2	60	0.077778	0.033333	0.16250	0.052083	0.380435
LAH	3	2	90	0.055556	0.022222	0.53750	0.104167	0.369565
LAH	3	3	15	0.277778	0.022222	0.15000	0.052083	0.375000
LAH	3	3	30	0.366667	0.022222	0.12500	0.052083	0.385870
LAH	3	3	45	0.055556	0.155556	0.13750	0.072917	0.478261
LAH	3	3	60	0.066667	0.233333	0.13125	0.083333	0.483696
LAH	3	3	90	0.066667	0.122222	0.13125	0.072917	0.353261
LAH	3	4	15	0.833333	0.033333	0.06250	0.031250	0.380435
LAH	3	4	30	0.766667	0.044444	0.05625	0.020833	0.331522
LAH	3	4	45	0.066667	0.122222	0.08125	0.041667	0.385870
LAH	3	4	60	0.077778	0.066667	0.15625	0.072917	0.385870
LAH	3	4	90	0.077778	0.111111	0.13750	0.072917	0.347826
LAH	3	5	15	0.666667	0.033333	0.11250	0.041667	0.347826
LAH	3	5	30	0.766667	0.033333	0.09375	0.041667	0.380435
LAH	3	5	45	0.033333	0.111111	0.13125	0.052083	0.407609
LAH	3	5	60	0.044444	0.122222	0.10000	0.052083	0.391304
LAH	3	5	90	0.033333	0.066667	0.10000	0.020833	0.304348

TABLE XX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_H2OK	PHH2O	PHKCL	PCTCLAY
LAH	3	1	15	0.0576923	4.9	3.9	9.2
LAH	3	1	30	0.0256410	5.0	3.9	13.2
LAH	3	1	45	0.0288462	5.9	5.0	18.2
LAH	3	1	60	0.0224359	6.5	5.3	16.2
LAH	3	1	90	0.0128205	7.1	5.9	22.2
LAH	3	2	15	0.0416667	4.9	3.8	13.2
LAH	3	2	30	0.0384615	4.8	3.9	14.2
LAH	3	2	45	0.0352564	6.2	5.0	18.2
LAH	3	2	60	0.0192308	6.9	5.7	38.2
LAH	3	2	90	0.0256410	7.9	7.3	35.2
LAH	3	3	15	0.0737179	5.6	4.9	9.2
LAH	3	3	30	0.0512821	5.0	4.1	12.2
LAH	3	3	45	0.0416667	6.3	5.1	14.2
LAH	3	3	60	0.0352564	6.6	5.4	19.2
LAH	3	3	90	0.0192308	6.9	6.0	21.2
LAH	3	4	15	0.0352564	5.1	3.9	7.2
LAH	3	4	30	0.0320513	5.2	4.0	9.2
LAH	3	4	45	0.0352564	5.9	4.7	13.2
LAH	3	4	60	0.0416667	6.1	5.0	13.2
LAH	3	4	90	0.0256410	6.4	5.3	18.2
LAH	3	5	15	0.0641026	5.0	4.0	11.2
LAH	3	5	30	0.0416667	4.9	3.9	15.2
LAH	3	5	45	0.0384615	6.0	4.8	14.2
LAH	3	5	60	0.0224359	6.5	5.2	15.2
LAH	3	5	90	0.0096154	6.9	5.6	23.2

TABLE XX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_KCLAL	ME_H2OAL	ME_H2OCA	ME_H2OMG	ME_H2ONA
LAH	4	1	15	0.78889	0.000000	0.06875	0.0208333	0.315217
LAH	4	1	30	1.36667	0.011111	0.07500	0.0208333	0.364130
LAH	4	1	45	0.36667	0.011111	0.08750	0.0208333	0.353261
LAH	4	1	60	0.02222	0.155556	0.09375	0.0312500	0.342391
LAH	4	1	90	0.03333	0.133333	0.08750	0.0312500	0.358696
LAH	4	2	15	1.00000	0.000000	0.09375	0.0312500	0.380435
LAH	4	2	30	1.32222	0.000000	0.08125	0.0208333	0.380435
LAH	4	2	45	0.05556	0.044444	0.13750	0.0416667	0.369565
LAH	4	2	60	0.05556	0.044444	0.50000	0.0833333	0.440217
LAH	4	2	90	0.05556	0.200000	0.13750	0.0625000	0.375000
LAH	4	3	15	1.18889	0.011111	0.06250	0.0208333	0.396739
LAH	4	3	30	0.46667	0.011111	0.06875	0.0208333	0.407609
LAH	4	3	45	0.04444	0.100000	0.20625	0.0625000	0.440217
LAH	4	3	60	0.05556	0.100000	0.10625	0.0416667	0.391304
LAH	4	3	90	0.02222	0.033333	0.10625	0.0520833	0.336957
LAH	4	4	15	0.91111	0.011111	0.07500	0.0208333	0.326087
LAH	4	4	30	1.12222	0.022222	0.06875	0.0208333	0.391304
LAH	4	4	45	0.07778	0.100000	0.09375	0.0416667	0.429348
LAH	4	4	60	0.04444	0.133333	0.10000	0.0416667	0.380435
LAH	4	4	90	0.03333	0.255556	0.09375	0.0520833	0.385870
LAH	4	5	15	0.72222	0.022222	0.08125	0.0312500	0.413043
LAH	4	5	30	0.50000	0.044444	0.07500	0.0312500	0.364130
LAH	4	5	45	0.05556	0.122222	0.08750	0.0312500	0.342391
LAH	4	5	60	0.03333	0.055556	0.08750	0.0312500	0.402174
LAH	4	5	90	0.03333	0.055556	0.08750	0.0416667	0.353261

TABLE XX (Continued)

LOC	QUAD	HOLE	DEPTH	ME_H2CK	PHH2O	PHKCL	PCTCLAY
LAH	4	1	15	0.0256410	4.9	3.9	4.2
LAH	4	1	30	0.0192308	4.9	3.8	5.2
LAH	4	1	45	0.0256410	5.4	4.1	9.2
LAH	4	1	60	0.0352564	6.2	5.0	13.2
LAH	4	1	90	0.0224359	6.2	4.9	13.2
LAH	4	2	15	0.0416667	4.7	3.8	7.2
LAH	4	2	30	0.0192308	5.0	3.8	9.2
LAH	4	2	45	0.0192308	5.7	4.4	13.2
LAH	4	2	60	0.0641026	6.3	5.1	9.2
LAH	4	2	90	0.0160256	6.9	5.6	10.2
LAH	4	3	15	0.0096154	4.8	3.8	3.2
LAH	4	3	30	0.0096154	5.3	4.0	8.2
LAH	4	3	45	0.0256410	6.3	5.0	9.2
LAH	4	3	60	0.0096154	6.6	5.2	10.2
LAH	4	3	90	0.0032051	6.9	5.4	19.2
LAH	4	4	15	0.0160256	4.8	3.8	4.2
LAH	4	4	30	0.0086538	5.0	3.8	6.2
LAH	4	4	45	0.0108974	5.7	4.4	10.2
LAH	4	4	60	0.0080128	6.4	5.0	9.2
LAH	4	4	90	0.0096154	6.9	5.3	13.2
LAH	4	5	15	0.0128205	4.7	3.8	4.2
LAH	4	5	30	0.0064103	5.0	3.9	9.6
LAH	4	5	45	0.0096154	6.1	4.8	9.6
LAH	4	5	60	0.0064103	6.3	5.0	7.6
LAH	4	5	90	0.0048077	6.8	5.5	11.6

TABLE XXI

CHEMICAL ANALYSIS DATA ON CARRIER AND LAHOMA SOILS

Loc	Quad	Hole	Depth	Me_NH_4Ca	Me_NH_4Mg	Me_NH_4Na	Me_NH_4K	PctOM	CEC
Car	2	4	15	3.0625000	0.81770833	0.09945652	0.676282051	1.45000000	6.8000000
Car	2	4	30	8.9062500	2.22916667	0.10706522	0.541666667	1.58000000	12.1000000
Car	2	4	45	10.5312500	2.86979167	0.13043478	0.416666667	1.71000000	14.0000000
Car	2	4	60	11.7437500	3.59375000	0.15706522	0.423076923	1.24000000	15.5000000
Car	2	4	90	12.1437500	3.99479167	0.17391304	0.410256410	1.04000000	16.5000000
Car	3	2	15	3.6812500	1.17708333	0.16847826	0.793269231	1.62000000	7.9000000
Car	3	2	30	8.3250000	2.92708333	0.16576087	0.429487179	1.51000000	12.9000000
Car	3	2	45	10.1187500	4.49479167	0.28260870	0.365384615	1.24000000	16.4000000
Car	3	2	60	10.2562500	5.03125000	0.27989130	0.373397436	0.90000000	16.4000000
Car	3	2	90	10.6875000	5.74479167	0.42119565	0.383012821	0.76000000	17.5000000
Lah	1	1	15	3.4000000	1.81250000	0.17119565	0.379807692	0.95000000	7.2000000
Lah	1	1	30	5.6187500	3.69791667	0.22282609	0.294871795	0.63000000	11.2000000
Lah	1	1	45	10.1812500	6.32812500	0.59239130	0.328525641	0.50000000	18.0000000
Lah	1	1	60	13.7625000	7.24479167	1.72826087	0.394230769	0.61000000	24.5000000
Lah	1	1	90	10.2062500	7.26041667	2.95380435	0.342948718	0.67000000	23.3000000
Lah	3	5	15	4.6500000	1.32812500	0.12445652	0.660256410	1.81000000	7.5000000
Lah	3	5	30	5.0250000	1.44791667	0.11141304	0.532051282	1.47000000	8.4000000
Lah	3	5	45	7.8562500	2.15104167	0.11250000	0.435897436	1.33000000	10.9000000
Lah	3	5	60	9.2625000	2.71354167	0.11195652	0.383012821	1.04000000	12.0000000
Lah	3	5	90	11.5312500	4.03645833	0.12228261	0.376602564	1.05000000	15.4000000

TABLE XXII

PARTICLE SIZE ANALYSIS AND TEXTURAL CLASSIFICATION DATA FROM CARRIER, LAHOMA, HEALY AND VIRGIN SOILS

Sample Number	% Sand	% Clay	% Silt	Textural Classification
		Carrier Soil Samples		
452	26.40	12.60	61.00	silt loam
453	20.40	18.60	61.00	silt loam
454	19.40	23.60	57.00	silt loam
455	20.40	24.60	55.00	silt loam
456	21.40	36.60	42.00	clay loam
457	27.40	9.60	63.00	silt loam
458	24.40	11.60	64.00	silt loam
459	22.40	22.60	55.00	silt loam
460	21.40	31.60	47.00	clay loam
461	20.40	40.60	39.00	clay
462	24.40	12.60	63.00	silt loam
463	21.40	12.60	66.00	silt loam
464	22.40	13.60	64.00	silt loam
465	22.40	31.60	46.00	clay loam
466	17.40	45.60	37.00	clay
467	23.40	15.80	60.80	silt loam
468	24.20	15.80	60.00	silt loam
469	23.20	18.80	58.00	silt loam
470	24.20	21.80	54.00	clay loam
471	20.20	34.60	45.20	silty clay loam
472	23.20	13.60	63.20	silt loam
473	26.40	13.60	60.00	silt loam
474	22.40	27.60	50.00	clay loam
475	20.40	36.60	43.00	clay loam
476	20.40	45.60	34.00	clay
477	26.40	12.60	61.00	silt loam
478	25.40	14.60	60.00	silt loam
479	16.20	22.60	61.20	silt loam
480	20.20	29.60	50.20	silty clay loam
481	16.20	46.60	37.20	clay

TABLE XXII (Continued)

Sample Number	% Sand	% Clay	% Silt	Textural Classification
482	24.20	13.60	62.20	silt loam
483	23.40	15.60	61.00	silt loam
484	20.40	27.60	52.00	clay loam
485	22.40	21.60	46.00	silt loam
486	19.40	44.60	36.00	clay
487	26.40	13.60	60.00	silt loam
488	22.40	11.60	66.00	silt loam
489	22.40	19.60	58.00	silt loam
490	21.40	28.60	50.00	clay loam
491	17.60	42.60	39.80	clay
492	24.60	15.60	59.80	silt loam
493	19.60	17.60	62.80	silt loam
494	20.60	24.60	54.80	silt loam
495	20.60	26.60	52.80	clay loam
496	21.60	29.60	48.80	clay loam
497	23.60	15.60	60.80	silt loam
498	23.60	19.60	56.80	silt loam
499	23.60	21.60	54.80	silt loam
500	23.60	21.60	54.80	silt loam
501	24.60	29.60	45.80	clay loam
502	21.60	18.60	59.80	silt loam
503	20.40	21.60	58.00	silt loam
504	20.40	19.60	60.00	silt loam
505	18.40	27.60	54.00	silty clay loam
506	19.40	33.60	47.00	silty clay loam
507	19.40	20.60	60.00	silt loam
508	19.40	21.60	59.00	silt loam
509	17.40	27.60	55.00	silty clay loam
510	17.40	29.60	53.00	silty clay loam
511	18.40	34.60	47.00	silty clay loam
512	20.40	19.60	60.00	silt loam
513	18.40	21.60	60.00	silt loam
514	18.40	20.60	61.00	silt loam
515	18.60	25.40	56.00	silt loam
516	16.60	30.40	53.00	silty clay loam
517	22.60	17.40	60.00	silt loam
518	20.60	19.40	60.00	silt loam
519	19.60	25.40	55.00	silt loam
520	18.60	30.40	51.00	silty clay loam
521	19.60	32.40	48.00	silty clay loam

TABLE XXII (Continued)

Sample Number	% Sand	% Clay	% Silt	Textural Classification
522	22.60	17.40	60.00	silt loam
523	20.60	19.40	60.00	silt loam
524	17.60	23.40	59.00	silt loam
525	17.60	27.40	55.00	silty clay loam
526	16.60	35.40	48.00	silty clay loam
527	19.80	21.40	58.80	silt loam
528	17.80	24.40	57.80	silt loam
529	17.80	27.40	54.80	silty clay loam
530	19.80	31.40	48.80	silty clay loam
531	18.80	42.40	38.80	clay
532	21.80	18.40	59.80	silt loam
533	19.80	19.40	60.80	silt loam
534	18.80	25.40	55.80	silt loam
535	18.80	30.40	50.80	silty clay loam
536	14.80	47.40	37.80	clay
537	21.80	19.40	58.80	silt loam
538	20.80	21.40	57.80	silt loam
539	17.40	26.60	56.00	silt loam
540	17.40	31.60	51.00	silty clay loam
541	16.40	44.60	39.00	clay
542	22.40	13.60	64.00	silt loam
543	21.40	17.60	61.00	silt loam
544	21.40	22.60	56.00	silt loam
545	20.40	28.60	51.00	clay loam
546	18.40	41.60	40.00	clay
547	22.40	17.60	60.00	silt loam
548	21.40	19.60	59.00	silt loam
549	20.40	23.60	56.00	silt loam
550	17.40	33.60	49.00	silty clay loam
551	16.60	44.60	38.80	clay
		Lahoma Soil Samples		
552	62.80	13.40	23.80	sandy loam
553	60.80	17.40	21.80	sandy loam
554	48.80	23.40	27.80	sandy clay loam
555	28.80	25.40	45.80	loam
556	22.80	27.40	49.80	clay loam

TABLE XXII (Continued)

Sample Number	% Sand	% Clay	% Silt	Textural Classification
557	74.80	9.40	15.80	sandy loam
558	72.80	9.40	17.80	sandy loam
559	60.80	17.48	21.72	sandy loam
560	62.80	17.48	19.72	sandy loam
561	64.80	19.48	15.72	sandy loam
562	62.80	13.48	23.72	sandy loam
563	56.80	17.48	25.72	sandy loam
564	52.80	21.48	25.72	sandy clay loam
565	54.80	17.48	27.72	sandy loam
566	54.80	23.48	21.72	sandy clay loam
567	66.80	9.48	23.72	sandy loam
568	66.80	15.48	17.72	sandy loam
569	64.80	17.48	17.72	sandy loam
570	48.80	25.48	25.72	sandy clay loam
571	50.80	17.48	31.72	loam
572	64.80	13.48	21.72	sandy loam
573	56.80	17.48	25.72	sandy loam
574	48.80	19.48	31.72	loam
575	46.80	29.48	23.72	sandy clay loam
576	49.60	27.60	22.80	sandy clay loam
577	72.40	5.60	22.00	sandy loam
578	72.40	8.60	19.00	sandy loam
579	71.40	9.60	19.00	sandy loam
580	76.40	10.40	13.20	sandy loam
581	74.60	10.40	15.00	sandy loam
582	80.60	5.40	14.00	loamy sand
583	76.60	9.40	14.00	sandy loam
584	76.60	11.40	12.00	sandy loam
585	82.60	9.40	8.00	loamy sand
586	80.60	10.40	9.00	loamy sand
587	76.60	4.40	19.00	loamy sand
588	74.60	5.60	19.80	sandy loam
589	69.60	9.60	20.80	sandy loam
590	76.60	9.60	13.80	sandy loam
591	75.60	9.60	14.80	sandy loam
592	80.60	3.60	15.80	loamy sand
593	79.60	5.60	14.80	loamy sand
594	82.60	7.40	10.00	loamy sand
595	88.60	7.40	4.00	loamy sand
596	77.60	7.40	15.00	loamy sand

TABLE XXII (Continued)

Sample Number	% Sand	% Clay	% Silt	Textural Classification
597	72.60	4.40	23.00	sandy loam
598	67.60	7.40	25.00	sandy loam
599	63.60	9.40	27.00	sandy loam
600	64.80	9.20	26.00	sandy loam
601	68.80	11.20	20.00	sandy loam
602	58.80	9.20	32.00	sandy loam
603	47.80	13.20	39.00	loam
604	37.80	18.20	44.00	loam
605	38.80	16.20	45.00	loam
606	41.80	22.20	36.00	loam
607	50.80	13.20	36.00	loam
608	48.80	14.20	37.00	loam
609	47.80	18.20	34.00	loam
610	31.80	38.20	30.00	clay loam
611	35.80	35.20	29.00	clay loam
612	52.80	9.20	38.00	sandy loam
613	43.80	12.20	44.00	loam
614	46.80	14.20	39.00	loam
615	41.80	19.20	39.00	loam
616	40.80	21.20	38.00	loam
617	71.80	7.20	21.00	sandy loam
618	65.80	9.20	25.00	sandy loam
619	46.80	13.20	40.00	loam
620	36.80	13.20	50.00	loam
621	33.80	18.20	48.00	loam
622	43.80	11.20	45.00	loam
623	47.80	15.20	37.00	loam
624	51.00	14.20	34.80	loam
625	55.00	15.20	29.80	sandy loam
626	48.00	23.20	28.80	loam
627	83.00	4.20	12.80	loamy sand
628	80.00	5.20	14.80	loamy sand
629	70.00	9.20	20.80	sandy loam
630	56.00	13.20	30.80	sandy loam
631	52.00	13.20	34.80	sandy loam
632	77.00	7.20	15.80	sandy loam
633	74.00	9.20	16.80	sandy loam
634	69.00	13.20	17.80	sandy loam
635	74.00	9.20	16.80	sandy loam
636	63.80	10.20	26.00	sandy loam

TABLE XXII (Continued)

Sample Number	% Sand	% Clay	% Silt	Textural Classification
637	87.80	3.20	9.00	sand
638	75.80	8.20	16.00	sandy loam
639	75.80	9.20	15.00	sandy loam
640	74.80	10.20	15.00	sandy loam
641	52.80	19.20	28.00	sandy loam
642	89.80	4.20	6.00	sand
643	84.80	6.20	9.00	loamy sand
644	79.80	10.20	10.00	loamy sand
645	78.80	9.20	12.00	loamy sand
646	51.80	13.20	35.00	sandy loam
647	86.80	4.20	9.00	loamy sand
648	78.40	9.60	12.00	sandy loam
649	79.40	9.60	11.00	sandy loam
650	83.40	7.60	9.00	loamy sand
651	57.40	11.60	31.00	sandy loam
		Healy Soil Samples		
652	26.40	12.60	61.00	silt loam
653	22.40	13.60	64.00	silt loam
654	22.40	13.60	64.00	silt loam
655	22.40	18.60	59.00	silt loam
656	25.40	25.60	49.00	loam
		Virgin Soil Samples		
700	21.60	13.60	64.80	silt loam
701	21.60	15.60	62.80	silt loam
702	23.60	18.60	57.80	silt loam
703	22.60	21.60	55.80	silt loam
704	19.60	25.60	54.80	silt loam
705	26.60	13.60	59.80	silt loam
706	22.60	17.60	59.80	silt loam
707	21.60	21.60	56.80	silt loam
708	21.60	23.60	54.80	silt loam
709	20.60	25.60	53.80	silt loam
710	22.60	14.60	62.80	silt loam
711	20.40	15.60	64.00	silt loam
712	20.40	18.60	61.00	silt loam
713	20.40	23.60	56.00	silt loam
714	20.40	28.60	51.00	clay loam

TABLE XXII (Continued)

Sample Number	% Sand	% Clay	% Silt	Textural Classification
715	23.40	11.60	65.00	silt loam
716	22.40	15.60	62.00	silt loam
717	21.40	19.60	59.00	silt loam
718	20.40	21.60	58.00	silt loam
719	22.40	23.60	54.00	silt loam
720	21.40	13.60	65.00	silt loam
721	21.40	13.60	65.00	silt loam
722	20.40	18.60	61.00	silt loam
723	20.40	21.60	58.00	silt loam
724	22.40	25.60	52.00	silt loam

TABLE XXIII

EXTRACTABLE CATION DATA FROM THE HEALY AND VIRGIN SOILS LEACHED WITH INCREMENTS OF 100 POUNDS NITROGEN PER ACRE APPLIED AS NITRIC ACID AND AMMONIUM NITRATE SOLUTIONS

		Al meq/100g		Ca meq/100g		Mg meq/100g		Na meq/100g		K meq/100g	
Depth	Inc.	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3
						Healy Soil					
0-15	1	5.24	.04	4.22	.54	1.27	.22	.12	.12	.62	.38
15-30		5.35	.04	6.53	.73	1.94	.28	.13	.10	.47	.25
30-45		5.46	.04	8.93	1.02	3.54	.43	.17	.11	.35	.16
45-60		6.49	.04	9.93	1.08	3.91	.50	.20	.15	.31	.13
60-90		6.78	.04	10.71	1.09	4.60	.54	.18	.11	.34	.14
0-15	2	2.32	.02	.45	.33	.23	.12	.07	.12	.16	.19
15-30		2.41	.02	.77	.42	.33	.17	.16	.09	.09	.15
30-45		2.96	.05	1.05	.60	.55	.25	.07	.10	.11	.11
45-60		3.37	.05	1.19	.65	.62	.28	.07	.11	.11	.07
60-90		4.01	.07	1.15	.67	.80	.33	.06	.11	.18	.08
0-15	3	2.03	.04	.22	.23	.17	.08	.05	.08	.13	.10
15-30		2.53	.04	.17	.30	.28	.12	.03	.09	.13	.08
30-45		3.37	.12	.39	.41	.35	.17	.03	.04	.14	.07
45-60		3.60	.11	.25	.45	.37	.20	.17	.10	.16	.07
60-90		3.76	.14	.46	.47	.40	.23	.06	.06	.14	.07

TABLE XXIII (Continued)

		Al meq/100g		Ca meq/100g		Mg meq/100g		Na meq/100g		K meq/100g	
Depth	Inc.	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3
0-15	4	1.37	.04	.20	.18	.15	.07	.03	.06	.09	.06
15-30		1.74	.09	.22	.27	.18	.10	.06	.16	.11	.06
30-45		2.59	.18	.34	.34	.25	.15	.06	.10	.12	.05
45-60		2.46	.11	.15	.37	.23	.17	.05	.10	.11	.04
60-90		2.59	.09	.28	.39	.27	.18	.05	.08	.12	.06
0-15	5	1.18	.02	.15	.17	.15	.07	.02	.10	.09	.05
15-30		1.68	.02	.71	.22	.18	.08	.02	.10	.09	.05
30-45		2.62	.12	.40	.31	.25	.13	.04	.13	.12	.05
45-60		2.30	.05	.41	.36	.22	.15	.03	.23	.10	.05
60-90		2.44	.04	.11	.33	.30	.17	.07	.10	.11	.04
0-15	6	.98	.04	.25	.18	.13	.07	.03	.09	.08	.04
15-30		1.28	.12	.10	.22	.15	.08	.05	.05	.08	.04
30-45		2.02	.16	.12	.31	.20	.13	.04	.10	.10	.05
45-60		1.78	.07	.10	.33	.17	.15	.02	.11	.10	.04
60-90		1.80	.11	.31	.34	.20	.17	.09	.08	.05	.04
0-15	7	.87	.07	.24	.15	.13	.05	.06	.04	.07	.03
15-30		1.16	.05	.06	.19	.15	.07	.04	.06	.07	.03
30-45		1.85	.16	.08	.29	.18	.12	.02	.10	.10	.04
45-60		1.62	.11	.10	.30	.17	.13	.01	.10	.08	.04
60-90		1.61	.07	.14	.30	.17	.15	.03	.10	.09	.03
0-15	8	.80	.02	.08	.12	.12	.05	.03	.10	.06	.03
15-30		1.05	.04	.10	.13	.13	.07	.02	.10	.06	.04
30-45		1.71	.18	.08	.19	.17	.08	.01	.05	.09	.04
45-60		1.50	.07	.26	.21	.15	.10	.02	.08	.08	.04
60-90		1.46	.07	.29	.22	.17	.10	.08	.05	.08	.04

TABLE XXIII (Continued)

Depth	Inc.	Al meq/100g		Ca meq/100g		Mg meq/100g		Na meq/100g		K meq/100g	
		HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3
0-15	9	.62	.02	.76	.11	.33	.05	.51	.04	.27	.03
15-30		.78	.04	.28	.13	.17	.05	.29	.07	.12	.03
30-45		1.28	.12	.51	.19	.27	.08	.31	.09	.24	.04
45-60		1.21	.11	.22	.24	.10	.10	.08	.09	.07	.04
60-90		1.23	.07	.47	.21	.25	.10	.32	.08	.26	.04
0-15	10	.78	.04	.46	.11	.27	.05	.32	.10	.24	.03
15-30		1.03	.11	.10	.13	.12	.05	.10	.08	.06	.04
30-45		1.66	.14	.90	.18	.28	.08	.59	.03	.29	.04
45-60		1.46	.12	.48	.18	.28	.08	.31	.07	.21	.04
60-90		1.52	.07	.56	.19	.35	.10	.35	.10	.27	.04
0-15	11	.87	.04	.10	.10	.17	.05	.08	.04	.06	.03
15-30		1.12	.05	.42	.12	.33	.05	.30	.03	.22	.03
30-45		1.78	.11	.54	.18	.40	.08	.46	.10	.31	.04
45-60		1.62	.07	.60	.17	.45	.08	.47	.06	.24	.03
60-90		1.80	.07	.56	.18	.40	.08	.33	.08	.28	.03
0-15	12	.82	.02	.13	.10	.08	.05	.10	.07	.05	.03
15-30		1.07	.05	.51	.12	.23	.05	.28	.05	.25	.03
30-45		1.52	.07	.72	.12	.89	.08	.56	.08	.22	.03
45-60		1.43	.12	.46	.17	.23	.08	.32	.06	.23	.04
60-90		1.53	.07	.55	.18	.37	.08	.44	.03	.27	.04
						Virgin Soil					
0-15	1	.36	.02	9.57	.79	3.64	.23	1.05	.11	1.14	.58
15-30		.64	.04	8.04	.94	1.91	.30	.13	.10	.73	.43
30-45		.70	.04	7.75	.94	2.57	.40	.15	.11	.65	.36

TABLE XXIII (Continued)

Depth	Inc.	Al meq/100g		Ca meq/100g		Mg meq/100g		Na meq/100g		K meq/100g	
		HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3
45-60		.70	.04	8.42	.98	3.48	.48	.41	.17	.75	.32
60-90		.70	.04	8.26	1.08	3.39	.57	.12	.16	.49	.25
0-15	2	1.02	.09	3.28	.50	1.19	.13	.51	.14	.43	.29
15-30		1.23	.09	2.70	.54	.74	.17	.28	.12	.39	.24
30-45		1.43	.07	2.61	.59	.87	.23	.31	.11	.42	.22
45-60		1.55	.07	2.74	.61	1.04	.27	.34	.10	.32	.19
60-90		1.34	.00	3.05	.65	1.25	.32	.29	.11	.36	.17
0-15	3	1.34	.09	.73	.41	.22	.12	.11	.09	.15	.17
15-30		2.00	.05	.58	.44	.25	.13	.09	.13	.17	.16
30-45		2.41	.07	.88	.43	.40	.17	.31	.11	.38	.14
45-60		2.25	.04	.65	.47	.37	.20	.09	.10	.13	.13
60-90		2.68	.02	.79	.50	.50	.23	.10	.09	.16	.12
0-15	4	1.59	.07	.23	.35	.17	.10	.09	.11	.14	.11
15-30		2.00	.27	.17	.35	.17	.13	.10	.10	.12	.12
30-45		2.37	.18	.19	.36	.18	.15	.13	.09	.14	.10
45-60		2.50	.16	.20	.37	.27	.17	.07	.07	.14	.12
60-90		2.46	.18	.22	.42	.30	.20	.09	.08	.14	.09
0-15	5	1.61	.11	.13	.35	.15	.10	.10	.07	.11	.08
15-30		1.84	.18	.11	.31	.13	.08	.06	.10	.11	.07
30-45		2.09	.21	.54	.31	.32	.13	.32	.08	.25	.08
45-60		2.32	.07	1.01	.33	.26	.13	.96	.10	.38	.08
60-90		2.48	.04	.46	.36	.33	.15	.29	.10	.26	.07

TABLE XXIII (Continued)

		Al meq/100g		Ca meq/100g		Mg meq/100g		Na meq/100g		K meq/100g	
Depth	Inc.	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3
0-15	6	1.21	.00	.09	.28	.13	.07	.08	.11	.08	.06
15-30		1.57	.30	.10	.29	.13	.10	.10	.10	.09	.08
30-45		1.78	.27	.44	.29	.27	.10	.31	.09	.26	.06
45-60		2.03	.21	.57	.30	.30	.13	.32	.11	.33	.07
60-90		2.00	.12	.32	.33	.27	.13	.27	.09	.24	.06
0-15	7	1.12	.04	.08	.28	.12	.07	.06	.09	.09	.04
15-30		1.43	.18	.11	.26	.13	.07	.10	.07	.09	.06
30-45		1.62	.21	.08	.26	.13	.10	.08	.09	.09	.06
45-60		1.89	.16	.48	.28	.30	.10	.32	.10	.26	.07
60-90		1.87	.05	.46	.29	.32	.12	.33	.08	.28	.06
0-15	8	1.07	.09	.53	.26	.28	.05	.36	.10	.28	.04
15-30		1.41	.27	.20	.25	.37	.13	.38	.10	.23	.05
30-45		1.55	.23	.46	.24	.27	.08	.31	.12	.26	.06
45-60		1.78	.12	.09	.25	.17	.10	.20	.07	.08	.06
60-90		1.82	.05	.07	.26	.17	.10	.10	.08	.09	.05
0-15	9	1.03	.07	.08	.24	.13	.05	.09	.12	.07	.03
15-30		1.28	.04	.39	.22	.28	.05	.47	.07	.37	.04
30-45		1.50	.14	.08	.24	.13	.08	.10	.11	.08	.04
45-60		1.62	.12	.34	.24	.25	.12	.37	.08	.18	.04
60-90		1.57	.00	.41	.26	.27	.10	.30	.09	.26	.04
0-15	10	.84	.09	.46	.23	.27	.05	.31	.05	.28	.03
15-30		1.12	.14	.07	.22	.12	.05	.09	.09	.07	.04
30-45		1.25	.16	.45	.22	.30	.07	.31	.08	.28	.04
45-60		1.43	.18	.09	.22	.13	.08	.08	.10	.09	.04
60-90		1.55	.09	.41	.24	.28	.08	.30	.10	.22	.04

TABLE XXIII (Continued)

Depth	Inc.	Al meq/100g		Ca meq/100g		Mg meq/100g		Na meq/100g		K meq/100g	
		HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3	HNO_3	NH_4NO_3
0-15	11	.71	.04	.09	.22	.15	.03	.08	.07	.06	.03
15-30		.96	.07	.52	.21	.32	.05	.34	.09	.24	.03
30-45		1.05	.07	.08	.20	.13	.05	.14	.09	.04	.04
45-60		1.21	.07	.08	.21	.15	.07	.13	.07	.06	.04
60-90		1.23	.05	.09	.22	.15	.08	.12	.08	.05	.03
0-15	12	.87	.04	.09	.20	.15	.03	.14	.08	.04	.03
15-30		1.12	.04	.08	.20	.15	.05	.16	.12	.04	.03
30-45		1.21	.20	.08	.20	.15	.05	.10	.09	.06	.04
45-60		1.44	.09	.08	.20	.17	.07	.14	.10	.05	.04
60-90		1.43	.07	.10	.22	.18	.07	.13	.06	.06	.04

VITA

Gordon Patrick King

Candidate for the Degree of

Doctor of Philosophy

Thesis: CHEMICAL PROPERTIES OF AN ACID PRODUCTIVE SOIL

Major Field: Soil Science

Biographical:

Personal Data: Born in Borger, Texas, February 14, 1948, the son of Mr. and Mrs. Gordon King.

Education: Attended the Phillips, Okmulgee, and Bartlesville Public Schools; graduated from College High School, Bartlesville, Oklahoma, in May 1966; received Associate of Arts degree from Junior College division of Central Pilgrim College, Bartlesville, Oklahoma, in May 1968; received the Bachelor of Science degree from Oklahoma State University in May 1970 with a major in Agronomy; entered graduate school, Oklahoma State University, in September 1971 and received the Master of Science degree in May 1973 with a major in Agronomy; reentered graduate school, Oklahoma State University in September 1977 and completed the requirements for the Doctor of Philosophy degree at Oklahoma State University in December 1981.

Experience: Graduate Research Assistant in the Agronomy Department from 1977 to 1981; worked at Phillips Petroleum Company in Bartlesville, Oklahoma, in drilling mud engineer and product evaluation chemist positions.

Professional Organizations: American Society of Agronomy; Soil Science Society of America; Crop Science Society of America; Clay Mineral Society.