

INCREASES IN EXCHANGEABLE
POTASSIUM UPON DRYING OF
SOILS AND CLAYS

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1961

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Date thesis is presented: August 4, 1960

Typed by Pat Allison

ACKNOWLEDGMENTS

The author gratefully acknowledges the advice offered by Dr. J Lowell Young and Dr. Moyle E. Harward throughout the conduct of this research and in the preparation of the manuscript.

The author expresses deepest appreciation to Dr. Roger G. Peterson, Dr. Horace B. Cheney, Dr. Max B. Williams and Dr. Lawrence A. Alban for reviewing the manuscript and offering sound advice throughout the course of study.

Appreciation to Mr. Arthur A. Theisen for assistance in X-ray diffraction analysis, to Dr. Ellis G. Knox for assistance with profile descriptions and to Mr. Wallace J. Wipper for assistance in routine chemical analyses is also expressed.

The cooperation of the Oregon State College Basic Research Committee, whose financial assistance in the form of a basic research grant contributed towards making this research possible, is appreciated.

The author also acknowledges the cooperation of the Soil and Water Conservation Research Division of the Agricultural Research Service of the U. S. Department of Agriculture.

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INCREASES IN EXCHANGEABLE
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INTRODUCTION

Potassium (K)¹ is an important plant nutrient and is generally found in association with layer silicate minerals of soil. The level of K in soil is related to the types of layer silicate minerals present. Since the types and amounts of layer silicate minerals present partially determine chemical properties of soils, everything that can be established about soil K will be a contribution.

The fact that K fixation occurs upon drying of certain layer silicate minerals, and therefore upon drying soils containing these minerals, has been well established and is generally accepted today. This fixation is considered to be a "trapping" of K ions between lattice layers of silicate minerals when the lattices contract upon dehydration. It is believed that K, NH_4 and some other ions are fixed by this mechanism because they have approximately the same diameter as depressions formed by hexagonal rings of oxygen atoms at the inner surfaces of layer silicate minerals. Larger ions do not allow the lattices to contract far enough to prevent re-entry of water molecules

¹Chemical symbols and/or elemental names rather than the more conventional oxides will be used in this thesis. The fact that K and some other elements exist largely in ionic forms in soil is realized and implied.

which expand the lattices. Smaller ions are not fixed because the lattices do not contract enough to prevent their migration or diffusion to external surfaces.

Expanding lattice layer silicates have high exchange capacities, marked shrinking and swelling properties, give rise to characteristic X-ray diffraction patterns, and have other characteristic properties. These minerals are classified on the basis of their properties and chemical composition. Expanding lattice type minerals include montmorillonoids.

Non-expanding lattice layer silicates have lower exchange capacities and do not exhibit marked shrinking and swelling properties. However, they do give rise to characteristic properties. Again, these minerals are classified on the basis of properties, and include illites, biotites and other micas.

It is now evident that a layer silicate may be expanded and classified into a group because of its properties and chemical composition. Then, K may be fixed by this mineral, its properties changed, and it would be reclassified as a member of another group. The different properties and corresponding nomenclature are a result of K fixation in many cases. One extremely important role of K in soils is therefore revealed.

Recently, it has been observed that exchangeable K increases upon drying some soils. Furthermore, a fixation of K under moist conditions in addition to K fixation upon drying has been observed. The implications of these phenomena are extensive in relation to layer silicate mineral conversion, K availability to plants, soil testing to determine the K status of soils, and K fertilization. Very little work has been done to establish the mechanism through which exchangeable K increases upon drying or decreases through wet fixation.

This thesis project was initiated in an attempt to elucidate some of the factors and mechanisms involved in the increase of exchangeable K upon drying. The work was done with the following objectives.

- A. To establish the conditions under which exchangeable K increases upon drying of soils and clays.
- B. To obtain some understanding of the extent and importance of this exchangeable K increase in several soil series.
- C. To relate the increases of exchangeable K upon drying to types of layer silicate clay² minerals.
- D. To suggest and perhaps establish a mechanism for the release of K upon drying soils and layer silicates.

²The terms clay, silt and sand used in this thesis refer to particle size fractions of less than 2 microns, 2 to 50 microns, and 50 microns to 2 millimeters, respectively.

In addition to the primary objectives, there are certain implications of the phenomena with respect to time of soil sampling for soil testing, availability of K to plants and interpretation of soil fertility research involving K.

REVIEW OF LITERATURE

Potassium fixation was discovered by Bernard Dyer (25) in 1895 during an attempt to determine the plant nutrients which might be available in soils. After adding various substances suspected to be plant nutrients including K to soil, Dyer successively leached the treated soil with citric acid. To his surprise, as well as to the surprise of others, citric acid leachings did not remove all the applied K. Other added materials were completely removed by the leaching. Dyer concluded that soils have properties which prevent removal of K by citric acid, and that these properties were peculiar to K alone. This non-leachable K later became known as fixed K.

Since Dyer's discovery, many investigators have observed that some soils and layer silicates fix K. Many attempts to measure K fixation under various conditions by soils and layer silicates have been made. Some investigators expressed concern that fertilizer K was lost by fixation and that such fertilization represented a loss to farmers. Others postulated that fixed K was or would become available to plants. Regardless of these arguments, very little work was done to establish facts concerning K fixation until the 1930's. At that time a rather large group of investigators began to study K fixation, K release,

crop response to K fertilization, effects of other substances and the effects of various conditions upon K fixation and release.

Potassium Fixation by Soils

One of the first extensive studies of K fixation was done by Volk (96) in 1934. He established that alternate wetting and drying of Wisconsin soils previously treated with one thousand pounds K per acre brought about rapid K fixation, and that K fixing capacities for different soils varied from none to one thousand pounds K per acre. Other results of his study indicated that very little K was fixed when soils were kept moist, and that ten wetting and drying cycles were necessary for maximum fixation. This indicated that drying or dehydration of soils is essential for K fixation. Many other investigators have concluded that most K fixation occurs as a result of drying (43, 44, 59, 90).

The idea that drying was essential for fixation brought about extensive research activities with objectives aimed at measuring K fixing capacities of various soils. Joffe and Kolodny (43, 44) postulated that perhaps the temperature increase usually associated with drying was really the factor causing fixation. They substantiated their idea by showing that maximum fixation occurred when soils were

dried at 200°C. Further support for the concept arose from observations that K, Rb, Ca, and possibly NH₄ were fixed in soil by heating in an autoclave (59). However, most investigators were not convinced that temperature increase was the factor since numerous studies had shown K fixation upon drying at room temperature.

Since K fixation occurred, it became necessary to identify K fixing components of soils. It was believed by many workers that phosphates of iron, aluminum, calcium, and magnesium were responsible. Others believed that clay minerals fixed K as well as various other colloidal materials present in soil. However, artificial mixtures of silica and alumina gels were shown not to fix K (96).

There are many factors which can increase or decrease K fixation by soils. Iron removal and liming highly acid soils both cause increases in K fixation. The increase from liming is coincident with increasing pH (47). This is supported by the fact that HCl leachings decrease and Ca(OH)₂ additions increase K fixation. Certainly the presence of other ions in the soil solution has marked effects. It has been generally accepted that NH₄ and K are fixed by the same mechanism in soils and layer silicates. Therefore, changes in the level of one ion in relation to the other causes changes in the relative quantities of each that will be fixed (36, 46, 70, 89).

Potassium Release by Soils

The postulate that fertilizer K was lost by K fixation was shown to be false when numerous investigators established that fixed K was available to plants (6, 8, 31, 64, 77). Wood and DeTurk (99) have suggested that K fixation is very important because it prevents loss of K by leaching and holds K in the rooting zone of plants where it is available. This idea is quite well accepted, but it fails to recognize the fact that some soils do not release K rapidly enough to support good plant growth even though their total K contents may be high. This introduces the idea that the rate of release of fixed K is of major importance in supplying K to plants rather than the total amount of fixed K in the soil.

Some studies have shown good correlations between exchangeable K and crop yield (17, 33, 64), and others have shown poor correlations (39, 55, 60, 74, 82). The use of stronger extractants such as HCl of various concentrations, boiling HNO_3 , and H_2SO_4 have been used to measure the K supplying power of the soils in attempts to find relationships between soil K and plant yield (6, 27, 31, 74, 77, 82). These strong reagents remove more K than the conventional NH_4OAc , NaOAc , and NaCl used to measure exchangeable K. In general, better relationships between soil K and crop response were found with the strong extractants,

however some evidence was presented which indicated that exchangeable K and K supplying power should be measured when determining K available to plants (82). Other methods, including continuous percolation employing exchange resins (61, 62), alternate leaching and storage using mild reagents such as NH₄OAc (9, 27, 75), and successive cropping (8, 17, 27, 31) have been used with varying degrees of success in correlating available K and plant yield. Numerous K release curves have appeared in the literature from these many studies.

Today, it is fairly well accepted that K equilibria exist in soils. These equilibria have been proposed by several investigators (6, 9, 31, 60), and the general form of the equation is usually expressed as



The equilibria differ from soil to soil and levels of each components can be altered by addition or removal of K. Usually when K is added to soils which fix K, fixation takes place rapidly and new equilibria are soon established. However, when soluble and exchangeable K are removed fixed K is released at a relatively slow rate, which is characteristic of the soil, and considerable time is often required before new equilibria are established. Therefore, the time required to establish new equilibria when existing equilibria are upset depends upon which components were changed.

This indicates the role of controlling factors other than concentrations (26, 62, 66, 67).

Potassium Fixation and Release by Clays

The capacity of soils to fix and supply K to plants was shown several years ago to be closely related to the per cent clay and the cation exchange capacity (33, 87, 101). This indicated that soil clays fixed and released K. Later, more direct studies established this fact (20, 22, 44, 46, 65, 95). It is presently accepted that only certain 2:1 layer silicate clay minerals fix K rather than all clays.

Vermiculite is considered to be the layer silicate mineral responsible for most K and NH₄ fixation in soils (21, 22, 51, 69). This is reasonable since vermiculite is a direct weathering product of micas, which are minerals containing fixed K. As K is removed from micas by cleavage, vermiculite is formed. It is apparent that if K is present, the reverse process may also occur very readily (10, 22, 68, 69).

Montmorillonoids and illites have both been found to fix K under certain conditions (19, 71). Some early work (95) indicated that K was fixed by kaolinite, but this fixation was very probably a result of vermiculite impurities in the sample. Certainly, any 2:1 layer silicate mineral with its d-axis expanded could fix K under certain

conditions. The K fixed by dehydrating some montmorillonoids may be readily released upon rehydration whereas that fixed by vermiculite and possibly other montmorillonoids would not. However, both minerals would fix K to a degree, depending upon the definition one wishes to use for fixed and exchangeable K. It is also possible that clays identified as illite, biotite, and/or some other micas could fix K. Conceivably, these minerals could be at a stage of weathering where they contained small packets of vermiculite which would fix applied K and be converted back to the mica form.

Layer silicate minerals which release K are the micas (10, 22, 68, 69). Specific micas studied most are biotite and illite. DeMumbrum and Hoover (22) reported that illite released K, but that considerable quantities of K were fixed by illite-vermiculite mixtures. They concluded that in these mixtures, vermiculite fixed the K which was released from illite. It is obvious, however, that as illite releases K it may be converted to a K fixing mineral.

Wet Fixation of K

Although drying was long considered essential for K fixation (43, 44, 58, 90), some isolated early work indicated that K fixation may occur under moist conditions (13, 23, 59). Some investigators have observed an initial K

fixation under moist conditions and then additional fixation upon drying. Stanford (88) proposed that wet fixation of K resulted through an unknown mechanism and that K fixation upon drying resulted through mineral lattice collapse which trapped K. Several other studies support Stanford's conclusions that the two types of K fixation occur. It appears that moist fixation is the dominate type in many soils (38, 57, 65, 73, 84).

Moist fixation of K occurs rapidly and is very sensitive to moisture content. With soil moisture contents of five per cent and below, this fixation is influenced by relative humidity (57). The fact that the process is very rapid may explain why more of the early work did not report wet fixation.

Increases in Exchangeable K Upon Drying

As previously explained, the conventional theory of K fixation contends that as certain layer silicates are dried, the lattice layers contract trapping K ions between them. This theory is still widely accepted today, and the same mechanism is advanced for fixation of K, NH₄, Rb, Cs, and some other substances. Today we know however, that this theory is not complete. It does not explain wet fixation of K, nor does it explain the fact that increases in exchangeable K occur upon drying of some soils.

Attoe (4) found that in nine out of ten untreated soils exchangeable K was increased with drying. Wet fixation of applied K occurred with nine of ten soils, and fixation of applied K upon drying occurred with all ten soils. Many other investigators have observed that exchangeable K either decreased or increased upon drying of soils (4, 5, 7, 56, 62, 84). In general, drying brings about increases in exchangeable K when levels of exchangeable K are low before drying, and decreases exchangeable K when levels are high. Since soils which release K upon drying will also fix added K, it is apparent that equilibria between various forms of K exist. Fixation of K upon drying is brought about by trapping, but wet fixation and release upon drying are not explained.

Increases in exchangeable K brought about by drying soil are sufficiently large to be significant in crop production if they occur under field conditions. Drying soils between crops released K, and increased both yields and K content of crops in the greenhouse (4, 53, 85). This increase in exchangeable K upon drying has certain implications in interpretations of many K fertilizer studies where crop response has been the measured factor. If in a greenhouse study, some pots dried sufficiently to release K, and others did not, it is obvious that results might be misinterpreted.

Increases in exchangeable K have been shown to result from freezing and thawing (9, 29, 78). Since freezing of soil is a drying process and since cycles of freezing and thawing bring about drying this is not surprising.

Effects of Al Compounds on K Fixation and Release

Additions of phosphate, which precipitates Fe and Al, to soils are sometimes accompanied by increases in K fixation (88). It has been suggested that Fe and especially Al ions and/or compounds occupy K fixation sites, and that as Fe and Al are precipitated by added phosphate, some of these sites previously occupied by Fe and Al ions and/or compounds become available for K fixation (38, 88).

Grim (32) suggested that as layer silicates are dried, Al moves from structural positions in the lattice to exchange sites. This involves degeneration of the crystal lattice with release of structural Al. Since Al ions are small enough to diffuse between layers of collapsed layer silicates (12), it is possible that this released Al might replace fixed K. This may or may not result in layer silicate mineral conversion because evidence that Al ions hold crystal layers together was presented (80, 81, 83) as well as evidence that Al precipitate was formed in inter-layer positions forcing the lattice to expand (83). Whether or not the lattice expands may depend upon pH, because it

was reported that below pH 4.4, Al ions held the crystal lattice collapsed, and as pH increased, Al precipitates formed forcing the lattice to expand. Decreased K fixation accompanied increased pH and Al precipitate formation. It was concluded that Al precipitates blocked collapse of the lattice, thus decreasing K fixation (83). It should be recognized that these Al precipitates blocking the lattice must not be Al phosphates since, as previously stated additions of phosphates increased K fixation in another investigation (88).

Additional evidence for the formation of Al precipitates between lattice layers resulting in decreased K fixation was reported by Rich and Obenshain (81). They added NH_4F , which complexes Al to a soluble form, to a mineral containing an interlayer material. This treatment removed the interlayer material and allowed the lattice to collapse and fix K.

The presence of vermiculite-chlorite integrades in soils indicates that Al compounds of various kinds form in interlayer positions of layer silicates. These interlayer materials could block lattice collapse and decrease K fixation as suggested (15, 49, 51, 81, 83). Removal of the interlayer material would allow an increase in K fixation. Conversely, formation of more interlayer material would decrease K fixation and possibly may cause K release.

EXPERIMENTAL METHODS AND MATERIALS

Identification of Standard and Soil Layer Silicate Materials

X-ray equipment. Identification of standard and soil minerals in this study was made using X-ray diffraction techniques. The X-ray unit used was a Norelco X-ray diffractometer, equipped with a Geiger counter and a Brown recorder. A Cu target was used to give CuK α X-ray radiation. A tube potential and current of 40 kilovolts and 20 milliamperes, respectively, were used. Divergence and scatter slits of 1/4° and a 0.006 inch receiving slit equipped with a Ni filter were used for all patterns.

Standard minerals. The standard layer silicate minerals used in this study were acquired from Ward's Natural Science Establishment, Inc., Rochester, New York, with the exception of some vermiculites. Characterization data were taken from the American Petroleum Industry (A.P.I.) report on reference clay minerals (3).

Preparation of standard minerals for X-ray analysis. Standard minerals were ground to pass through a 100 mesh sieve. Samples were placed in a cavity in an aluminum sample holder, and levelled by placing the flat side of a smooth piece of glass against the sample and the aluminum holder, and moving the glass in a circular motion. This

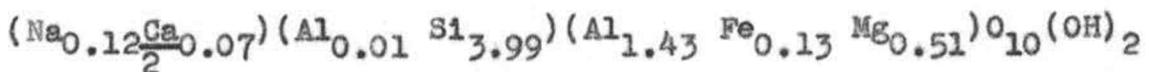
procedure brings about orientation of the mineral particles, and results in sharper and more intense peaks on the X-ray patterns.

This procedure was used so that the effects of controlled wetting and drying cycles on layer silicate mineral structure could be measured by X-ray diffraction without imposing additional treatments. Conventional procedures for preparing oriented specimens would impose additional wetting and drying as well as the use of dispersing reagents. Therefore, use of conventional methods might result in structural changes which are not associated with the initial treatments. This might result in the formulation of incorrect conclusions.

In addition to the less than 100 mesh samples of standard layer silicate minerals, some oriented specimen slides were prepared from the less than 2 micron size fraction. This was accomplished by dispersing samples in calgon solution (48) and separating the less than 2 micron fraction by centrifugation (41). Small aliquots of suspensions were deposited on glass slides and allowed to dry.

Sources, chemical composition and X-ray diffraction of standard minerals

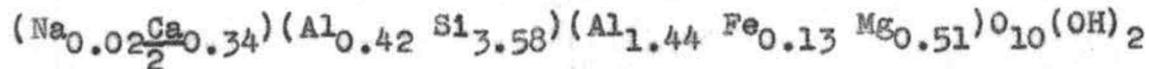
Montmorillonite 24. This montmorillonite is from Otay, California. It has the chemical formula,



It has only slight tetrahedral substitution of Al for Si but considerable octahedral substitution of Mg for Al. Ca and Na are interlayer ions. It has 4 per cent impurities consisting of quartz, orthoclase, and sericite with traces of dark materials (3).

X-ray diffraction patterns³ of the less than 100 mesh and the less than 2 micron size fractions were typical for montmorillonoid.

Montmorillonite 21. The source of this material was given as Chisholm Mine, Burns, Mississippi. It has the formula,



This mineral has considerable substitution in both the octahedral and tetrahedral layers. It is considered a high quality clay of the beidellite type with 8 to 10 per cent impurities consisting of quartz, sericite, orthoclase, and carbonaceous inclusions. Ca is the predominant interlayer cation (3).

X-ray diffraction patterns of both, the less than 100

³Typical X-ray diffraction patterns of various minerals reported by Brindley (14) and Grim (32) were used for comparison with patterns obtained in this study.

mesh and less than 2 micron fractions, were typical for montmorillonoid.

Illite 35. This is a micaceous mineral from Fithian, Illinois with the general formula,



It contains 12 per cent impurities consisting of sercite, quartz, plagioclase, pyrite, calcite, and traces of carbonaceous inclusions (3).

The X-ray diffraction patterns of the less than 100 mesh size fraction were poor, giving broad peaks with maxima at 10 \AA° . The clay size fraction gave typical 10 \AA° peaks but they were rather weak. K saturated samples gave a moderately sharp peak at 10.3 \AA° , and Ca saturated samples a broader peak at 10.5 \AA° . This shows a slight contraction of the basal spacings resulting from K saturation and indicates that perhaps some K depleted illite is present in this material (30).

Biotite 33. The source of this acid K, Mg, Fe, Al orthosilicate is given as Canada or North Carolina. Grim (32) states that biotite has the formula,



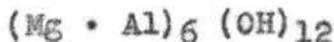
The X-ray diffraction patterns gave a very intense,

sharp peak at 10 A°.

Prochlorite 6. The source of this mineral was Vermont. It was described as an acid Mg, Fe, Al silicate. Prochlorite is a member of the chlorite group of minerals (32). It consists of alternate mica-like and brucite-like layers. The mica-like layer has the general composition,



and the brucite-like layer has the general composition,



X-ray diffraction patterns were typical for chlorite.

Vermiculite 1. This material was obtained by washing less than 100 mesh commercial zonalite three times a day for three days with 1N MgCl₂. A washing consisted of shaking for several hours, centrifuging, decanting and then adding fresh MgCl₂ solution. A mineral:solution ratio of approximately 1:10 was used. After MgCl₂ washing, the excess salt was removed by three water washings, the material was dried and ground to less than 100 mesh.

The source of the commercial zonalite was Northwest Insulation Company, Spokane, Washington.

The X-ray diffraction patterns gave a very intense 14.7 A° peak and a very weak 10 A° peak. This indicated that some mica was still present in the sample, but that

the dominant mineral was vermiculite. The 14.7 \AA° peaks obtained from this material as well as other vermiculites used in this study are from vermiculite and not chlorite because these peaks disappeared and intense 10 \AA° peaks appeared upon K saturation.

Vermiculite 2. This material was the commercial zonalite from Spokane which was used to prepare vermiculite 1. No treatment other than grinding to less than 100 mesh was applied to this sample.

X-ray diffraction analysis gave an intense 10 \AA° peak and a weak 14 \AA° peak. This indicated that the material contained predominantly mica with some vermiculite present.

Washing this micaceous material with MgCl_2 converts it to vermiculite as evidenced by preparation of vermiculite 1.

Vermiculite 3. This material was used as a packing material for glassware which we received. The source is unknown. The material was ground to less than 100 mesh with a Wiley mill and mortar and pestle.

The X-ray diffraction patterns gave 12.5 \AA° , 14.7 \AA° and 27.4 \AA° peaks, with the 14.7 \AA° peak being much more intense than the other two. This indicated that the material was predominantly vermiculite, but that perhaps impurities were present. The 27.4 \AA° peak indicated regular interstratification of vermiculite and the material giving the 12.5 \AA° peak. The 12.5 \AA° peak indicated the presence

of either Na saturated vermiculite (10) or randomly interstratified mica and vermiculite.

Vermiculite 4. This material was converted from vermiculite 3 by washing with $MgCl_2$ as described for the preparation of vermiculite 1.

The X-ray diffraction patterns showed a very intense 14.7 \AA° peak and very weak 12.5 \AA° and 27.4 \AA° peaks. Comparison of these patterns with those from vermiculite 3 indicated that $MgCl_2$ brought about some conversion because the relative intensity of the 14.7 \AA° peak to the other two had increased.

Vermiculite 5. The original material was obtained through Ward's Natural Science Establishment, Inc., from Libby, Montana. This material was placed in a beaker and enough H_2O_2 added to cover it. Action of the H_2O_2 caused flakes of material to rise to the surface as shown in a method by Jackson (41). As flakes came to the surface, they were skimmed off, washed, dried and ground.

X-ray diffraction patterns obtained were similar to those for vermiculite 3 indicating similar composition. The 12.5 \AA° and 27.4 \AA° peaks were relatively more intense in comparison with the 14.7 \AA° peak for this material than for vermiculite 3 indicating a smaller proportion of pure Mg vermiculite than in vermiculite 3.

Vermiculite 6. This material was obtained by

treating a sample from a Pikes Peak, Colorado granite deposit with H_2O_2 and skimming off vermiculite flakes which appeared on the surface as previously described.

The X-ray patterns showed 10 \AA° and 14.7 \AA° peaks indicating the presence of discrete mica and vermiculite.

Sample preparation for X-ray analyses of soil layer silicate clays.

For all soils except Nehalem and Tillamook organic matter was removed using H_2O_2 (48), and free iron oxides were removed by Mackenzie's method "a" (58). These samples were then dispersed in calgon (48) and the size fractions separated by sieving and centrifugation (41). Organic matter removal, free iron oxide removal, dispersion and size separation of Nehalem and Tillamook were done using Jackson's (41) method.

Samples of the 2-0.2 micron and the less than 0.2 micron size fractions were K saturated by two washings with 1 N KCl. Similar samples were Ca saturated with 1 N $CaCl_2$. Two water washings were used to remove excess salts. The samples were then stirred vigorously to suspend in a small quantity of water. Small aliquots of these suspensions were deposited on glass slides and allowed to dry. All slides were prepared in duplicate.

Prepared slides of Nehalem, Tillamook, Aiken and Cascade soils were dried at $65^{\circ}C$ for 1 hour after drying at room temperature. The slides were then scanned for X-ray

patterns. Then one slide of Ca saturated material from each soil was glycol solvated by placing it on rubber stoppers in a moisture can containing a small amount of ethylene glycol, replacing the lid, and heating at 65°C for 1 hour. Slides remained in the glycol atmosphere for at least 24 hours before scanning. Also, one slide of K-saturated material from each soil was heated at 550°C for 1 hour, and again scanned as soon as it was cool enough to handle.

All prepared slides of other soils were glycol solvated before scanning. One slide of solvated K saturated material from each soil was heated at 300°C for 1 hour and again scanned.

The reason for the use of various methods of sample preparation was that some of the work was done by other investigators at Oregon State College.⁴ These data were used when available.

Location, description and properties of soils.

Soil samples were collected from each horizon of eight soil series while soils were moist. Two profiles of the Aiken series were included. Soil profiles were examined and described at the time of sampling. The soil samples were used to characterize the variations in water soluble

⁴X-ray diffraction analyses of Nehalem and Tillamook soils were made by E. A. Jenne, Aiken soils by D. W. James, and Cascade soil by J. E. Yahner.

and exchangeable K upon drying and the mineralogy of the various soils. Some of these samples were used for laboratory wetting and drying cycle studies as described elsewhere in this thesis.

General descriptions and X-ray diffraction properties of these soils are given in the next few pages and in Table 1. Detailed profile descriptions, parent material and rainfall relationships, a summary of pertinent soil characteristics and mechanical analysis data are given in the Appendix.

Aiken soils. Ashton and Bonkowski farms, Linn County.

These soils are currently considered Aiken although studies in progress may lead to redefinition of the series. The soils are locally referred to as well-drained Reddish Brown Latosols and were developed from residuum derived from basalt or basalt-like material.

A vermiculite-chlorite integrade and possibly kaolin and a montmorillonoid layer silicate clays were identified throughout the profile at the Ashton location of Aiken. The fine clay fraction also contained kaolin in all horizons with the integrade occurring in the Ap and B₂₂ horizons. The surface horizon of the Bonkowski location contained kaolin, vermiculite-chlorite integrade, and possibly chlorite in the coarse clay fraction. No layer silicates

were evident in the fine clay fraction.⁵

In these soils the fine clay fraction accounts for approximately 80 per cent of the total clay. Since these soils contain quite high percentages of clay, and since only small to moderate quantities of layer silicates are present in the fine clay fraction, these soils apparently contain relatively large amounts of amorphous material. Very likely both allophane and residual Al and Fe oxides are present. However, further work would be necessary to verify this.

Chehalis soil. Horticulture farm, Linn County.
This is an alluvial soil from recent silty alluvium. Locally it is found on the flood plains of the Willamette River. It is well drained and is level.

A montmorillonoid was the predominant layer silicate clay mineral in both clay size fractions. Small amounts of vermiculite and kaolin are present in the coarse clay fraction. Layer silicate composition did not appear to change with depth.

The Chehalis soil represents some of Oregon's best agricultural soils.

Willamette soil. Near Peoria, Linn County. Willamette soil represents the well drained member of a drainage

⁵Personal communication, D. W. James, Department of Soils, Oregon State College, Corvallis, Oregon.

catena including Willamette, Woodburn, Amity and Dayton. These soils were derived from water deposited silts. Willamette soil represents important Agricultural soils and occurs on level or slight slopes.

Illite, montmorillonoid and kaolin layer silicate clay minerals were present in the coarse clay fraction of the Ap and C horizons. The fine clay fraction of the Ap horizon contains montmorillonoid, illite and possibly kaolin, but only montmorillonoid was present in this size fraction of the C horizon. This indicates a decrease in illite content with depth.

Amity soil. Near Waconda, Marion County. Amity soil was derived from old alluvium and is the imperfectly drained member of the drainage catena. There was no slope at this location.

Layer silicate clay mineralogy data was obtained on only the B₂₁ horizon of Amity. The coarse clay fraction contained montmorillonoid, illite, some interstratified material and possibly kaolin. The fine clay fraction contained montmorillonoid and interstratified material.

Dayton soil. Near Peoria, Linn County. Dayton soil is the poorly drained member of the drainage catena.

The coarse clay fraction of the Ap, B₂₂ and C horizons contained illite. Montmorillonoid was present in both size fractions of the C horizon and possibly present in the Ap

and B₂₂ horizons. Kaolin was found in the coarse clay fraction of the B₂₂ and C horizons, and was possibly present in the Ap horizon. Vermiculite was a possible constituent of the coarse clay fraction of the Ap and B₂₂ horizons. An interstratified material was found in the B₂₂ horizon and was possibly present in the Ap horizon.

Nehalem soil. Tillamook Naval Air Base, Tillamook County. This is a recent silty alluvial soil on the flood plain of the Trask River. It is well drained and on less than 1 per cent slope.

Montmorillonoid was the only layer silicate clay mineral identified in this soil. This mineral was present in all horizons.⁶ The presence of relatively large quantities of amorphous materials was evident as well as a relatively high organic matter content.

Tillamook soil. Tillamook Naval Air Base, Tillamook County. This is an Ando-like soil from old silty alluvium on a broad terrace above the present flood plain. It is level and well drained.

Montmorillonoid was identified in all horizons of the profile in both the coarse and fine clay fractions. The presence of weak 7 Å peaks indicated the presence of small amounts of kaolinite in the coarse clay fraction.

⁶Personal communication, E. A. Jenne, Department of Soils, Oregon State College, Corvallis, Oregon.

Illite was also a possible constituent.⁷ In addition to layer silicates, Tillamook soil evidently contained amorphous materials. It has high organic matter content.

Cascade soil. Lloyd farm, Columbia County. Cascade soil is locally referred to as a Reddish Brown Latosol and is developed from loess over water-deposited silts. It has a 10 per cent slope and is imperfectly drained.

The layer silicate clay minerals identified in the coarse clay fraction were vermiculite-chlorite or chlorite-montmorillonoid integrade and possibly kaolin in the Ap horizon, illite and the integrade in the A₃ and B₁ horizons and illite and montmorillonoid in the B₂ horizon. Illite content increased with depth.⁸ No layer silicates were definitely found in the less than 0.2 micron clay fraction except in the B₂ horizon where montmorillonoid was identified.

Walla Walla soil. Sherman County. This soil was derived from loess. It occurs on gently sloping upland with 8 per cent slope. The soil is well drained, and occurs under semiarid climate. Of the soils used in this study, Walla Walla is the only soil which represents eastern

⁷Personal communication, E. A. Jenne, Department of Soils, Oregon State College, Corvallis, Oregon.

⁸Personal communication, J. E. Yahner, Department of Soils, Oregon State College, Corvallis, Oregon.

Oregon soils. All other soils were from the Willamette Valley or the Oregon coast.

The coarse clay fraction of the A_{1p} horizon contained illite, montmorillonoid, vermiculite, and possibly some interstratified material. Definite identification of layer silicates in the less than 0.2 micron was not possible, but montmorillonoid, vermiculite and an interstratified material were recognized as possibilities.

The coarse clay fraction of the AC₂ horizon contained montmorillonoid, illite, and possibly kaolin. The less than 0.2 micron fraction of the same horizon contained montmorillonoid, illite and an interstratified material.

Table 1. X-ray diffraction properties of soils.

Soil	Horizon	Layer silicate clays present ¹						
		I	V	C	M	K	C-V	C-M
Aiken (Ashton)	A _p				P	*	*	
	B ₁				P	*	*	
	B ₂₁				P	*	*	
	B ₂₂				P	*	*	
Aiken (Bonkowski)	A _p			P		*	*	
Chehalis	A ₁		*		*	*		
	C ₁		P		*	*		
Willamette	A _p	*	P		*	*		
	C	*			*	*		
Amity	B ₂₁	*			*	*		*
Dayton	A ₁₁	*	P		P	P		
	B ₂₂	*	P		P	*		*
	C	*			*	*		*
Nehalem	A _{1p}				*			
	A ₁₂				*			
	C ₁				*			
	C ₃				*			

¹Meaning of symbols: I - illite; V - vermiculite; C - chlorite; M - montmorillonoid; K - kaolin; C-V - chlorite-vermiculite intergrade; C-M - chlorite-montmorillonoid intergrade; Int. - Interstratified; * - present; p - possibly present.

Table 1. X-ray diffraction properties of soils. (Cont'd)

Soil	Horizon	Layer silicate clays present						
		I	V	C	M	K	C-V	C-M
Tillamook	A _p	p			*	*		
	A ₁₂	p			*	*		
	B ₁	p			*	*		
	B ₂	p			*	*		
Cascade	A _p					p	*	p
	A ₃	*					*	p
	B ₁	*					*	p
	B ₂	*			*			
Walla Walla	A _{1p}	*	*		*			*
	AC ₂	*			*	*		*

Determination of Exchangeable K

Exchangeable⁹ K was determined by various extracting reagents for different studies in this thesis project. The extracting reagent used for each study will be given in the discussion of that study. The extraction procedure for all extracting reagents was the same.

Samples of 1 to 4 grams, depending upon the K level, were weighed into 50 milliliter polyethylene centrifuge tubes. Approximately 33 milliliters of extracting solution were placed in the tubes, the tubes stoppered and shaken for 5 minutes on a mechanical shaker. The sample tubes were then centrifuged at rates and times necessary to throw down the sample and leave clear supernatent extracts. The supernatent extracts were then filtered, using Whatman number 1 filter paper, into 100 milliliter volumetric flasks. Following the decanting, another 33 milliliters of extracting solution was added and the procedure repeated. A total of three washings was used giving nearly 100 milliliters of extract. The combined filtrates were made to volume, 100 milliliters, with the same extracting reagent.

The K contents of extracts were determined with a Beckman model DU flame spectrophotometer. Standard K

⁹In this thesis exchangeable K is defined as the K removed by the extracting reagent used and water soluble K is included since it would be removed by the extracting reagents.

solutions were made up using KCl dissolved in the extracting solution.

Determination of Water Soluble K

Water soluble K was determined in extracts from saturated soil samples. A saturated paste was made by mixing approximately 100 grams of soil and distilled water together with a spatula until a paste with only a few drops of excess water on the surface was obtained. Pastes were allowed to stand 4 hours. Extracts from these pastes were obtained with a suction apparatus using a water aspirator. K content was determined with a Beckman model DU flame spectrophotometer.

Determination of Moisture Content

Moisture content was determined on the dry weight bases for all samples. The samples were weighed in moisture cans of known weight, dried at 110°C for 48 hours and again weighed. The weight of moisture lost and the dry weight of soil were thus obtained.

In addition to regular moisture content, the per cent weight loss by heating 110°C dried samples at 200°C for 48 hours was also determined for some samples. The procedure used was the same as that for moisture content except the weight of the 110°C samples was used for calculating per

cent weight loss rather than the weight of samples heated at 200°C.

Moisture content percentage and percentage weight loss on 200°C heating were used to convert all K contents to the same basis of 110°C dried samples.

RESULTS AND DISCUSSION

Variations in Exchangeable K Upon Drying of Soils

Since no information was available on variations in exchangeable K content resulting from drying for Oregon soils, several important agricultural soils were selected for study of these variations. The soils studied were described in a previous section and their layer silicate clay mineral compositions were given.

Samples from each horizon of 9 soil profiles representing 8 soil series were obtained while soils were moist. These samples were brought to the laboratory and analyzed for exchangeable and water soluble K at various moisture levels. Analyses were made on field moist, air dried, 110°C oven dried and 200°C heated samples. 1 N NH₄OAc, pH 7.0 extracting reagent was used. These data and soil moisture data are presented in Table 2.

Increases in exchangeable K occurred upon air drying for all horizons of all soils except Nehalem A_{1p}, Tillamook Ap, Dayton A_{1l}, Cascade Ap, Willamette B₂ and C, and all horizons of Walla Walla. In many cases these increases were small, but nevertheless, they did occur. Very marked increases occurred in Dayton B₂₁, B₂₂, and C, and Cascade B₂. Moderate increases were found in lower horizons of Chehalis, Dayton A₁₂ and A₂, Tillamook A₁₂ and B₁,

Table 2. Variations in exchangeable K at several moisture levels as determined in NH₄OAc extract.

Horizon	Exchangeable K, me K/100g soil				Layer silicate clays ²	Soil moisture percentage ¹		
	Field moist	Air dried	110°C Oven dried	200°C heated		Field moist	Air dried	200°C heated
Aiken (Bonkowski)								
A _p	0.29	0.32	0.32	0.34	C*, K, C-V	5.8	4.8	3.5
B ₁	0.15	0.17	0.17	0.23		7.4	5.0	3.3
B ₂₁	0.16	0.16	0.18	0.22		9.8	4.6	2.7
B ₂₂	0.11	0.15	0.16	0.22		12.4	5.5	2.5
Aiken (Ashton)								
A _p	0.18	0.23	0.16	0.26	M*, K, C-V	27.0	5.5	5.6
B ₁	0.15	0.18	0.14	0.24	M*, K, C-V	26.1	5.5	4.7
B ₂₁	0.08	0.13	0.11	0.19	M*, K, C-V	25.2	5.5	3.8
B ₂₂	0.07	0.13	0.10	0.19	M*, K, C-V	59.9	5.9	3.4
Chehalis								
A ₁	0.47	0.49	0.38	0.48	V, M, K	11.2	5.0	4.4
A ₂	0.16	0.19	0.20	0.24	V*, M, K	10.8	4.6	2.7
C ₁	0.14	0.20	0.21	0.26		9.4	4.2	2.4
C	0.14	0.18	0.18	0.26		9.6	4.4	1.9

¹Soil moisture percentage was calculated on a 110°C dry weight basis.

²Meaning of symbols used: I - illite; V - vermiculite; C - chlorite; M - montmorillonoid; K - kaolinite; * - possibly present; C-V - chlorite-vermiculite intergrade; C-M - chlorite-montmorillonoid; Int. - Interstratification.

Table 2. Variations in exchangeable K at several moisture levels as determined in NH₄OAc extract (Cont'd.).

Horizon	Exchangeable K, me K/100g soil				Layer silicate clays	Soil moisture percentage		
	Field moist	Air dried	110°C Oven dried	200°C heated		Field moist	Air dried	200°C heated
Willamette								
A _p	2.00	2.10	1.95	1.93	I, V*, M, K	23.4	2.9	3.2
B ₁₁	1.81	1.85	1.60	1.58		17.1	2.2	1.8
B ₁₂	1.25	1.28	1.21	1.12		16.6	2.4	1.0
B ₂	1.34	1.28	1.29	1.26		26.2	5.0	1.1
C	0.71	0.59	0.81	0.82	I, M, K	25.3	4.8	0.8
Dayton								
A ₁₁	0.42	0.31	0.30	0.23	I, V*, M, K	21.1	2.4	2.7
A ₁₂	0.28	0.31	0.29	0.33		19.6	2.0	1.6
A ₂	0.15	0.18	0.18	0.20		19.3	2.7	1.6
B ₂₁	0.07	0.36	0.46	0.65		25.3	7.1	1.9
B ₂₂	0.08	0.34	0.45	0.58	I, V*, M*, K, Int.	16.6	6.6	1.5
C	0.05	0.32	0.39	0.53	I, M, K, Int.	23.8	5.3	1.4
Tillamook								
A _p	0.23	0.22	0.27	0.29	I*, M, K,	18.2	8.0	5.2
A ₁₂	0.20	0.22	0.25	0.28	I*, M, K,	28.8	8.7	7.5
B ₁	0.15	0.17	0.18	0.22	I*, M, K,	30.0	7.8	4.8
B ₂	0.11	0.12	0.14	0.16	I*, M, K,	29.8	8.0	4.2

Table 2. Variations in exchangeable K at several moisture levels as determined in NH₄OAc extract (Cont'd.).

Horizon	Exchangeable K, me K/100g soil				Layer silicate clays	Soil moisture percentage		
	Field moist	Air dried	110°C Oven dried	200°C heated		Field moist	Air dried	200°C heated
Nehalem								
A _{1p}	0.69	0.56	0.63	0.56	M,	14.2	7.8	6.1
A ₁₂	0.19	0.19	0.22	0.19	M,	18.8	8.0	5.1
C ₁	0.13	0.18	0.18	0.18	M,	20.2	7.5	3.9
C ₃	0.11	0.15	0.19	0.15	M,	28.2	8.0	4.2
Cascade								
A _p	0.14	0.12	0.12	0.14	K*, C-V, C-M*	3.6	2.9	2.9
A ₃	0.09	0.10	0.10	0.12	I, C-V, C-M*	4.0	2.7	1.6
B ₁	0.09	0.11	0.10	0.15	I, C-V, C-M*	5.0	1.8	1.1
B ₂	0.10	0.17	0.22	0.27	I, M,	8.8	2.9	1.0
Walla Walla								
A _{1p}	1.62	1.39	1.39	1.44	I, V, M, Int.	2.2	1.6	1.1
A ₁₂	1.45	1.30	1.33	1.31		2.8	1.6	0.9
AC ₁	1.35	1.22	1.22	1.21		3.0	2.0	0.6
AC ₂	1.66	1.39	1.37	1.19	I, M, K, Int.	6.8	1.8	0.7
Cca ₁	1.40	1.28	1.21	1.21		4.2	1.8	0.7
Cca ₂	1.34	1.20	1.16	1.16		5.2	2.0	0.7

Nehalem C₁, Aiken (Ashton) Ap, B₂₁ and B₂₂, and Aiken (Bonkowski) Ap horizons.

Oven drying at 110°C brought about additional increases in exchangeable K in some soils above the increases found with air drying. However, this was not consistent since all horizons of Aiken (Ashton), Chehalis Ap, Willamette Ap, B₁₁ and B₁₂, and Dayton A₁₂ gave increases in exchangeable K upon air drying and then fixed K upon 110°C oven drying. Furthermore the 12 soils which fixed K upon air drying released K upon 110°C oven drying excepting Dayton A₁₁, Cascade Ap and Walla Walla AC₂, Cca₁ and Cca₂ samples which fixed small amounts of K with oven drying.

Heating 110°C oven dried soils to 200°C for 48 hours resulted in increases in exchangeable K in most soils. However, decreases or no changes were observed in Willamette horizons, Nehalem horizons, all horizons of Walla Walla excepting the A_{1p}, and in the Dayton A₁₁ horizon.

In cases where the layer silicate clays were identified, it was evident that montmorillonoids were definitely or possibly present where K fixation occurred. This was true regardless of whether the K fixation occurred upon air drying, oven drying or heating. However, the presence of montmorillonoids did not always result in K fixation with drying since K was released in many cases where montmorillonoids were present.

Increases in exchangeable K were apparently independent of the types of layer silicate clays present. These increases occurred where montmorillonoids were present alone and in combination with illite and kaolin, and in combination with kaolin alone. Increases also occurred in soils where no montmorillonoids were identified and where chlorite-vermiculite intergrades were present. The largest increases were observed where montmorillonoid, illite, kaolin and probably vermiculite were identified.

Increases in water soluble K were found with nearly all soils, but these increases were very small because levels of soluble K were extremely low. The increases in soluble K with drying were less than 0.01 milliequivalents per 100 grams for nearly all samples. Increases of this magnitude are insignificant and are too small to account for variations in exchangeable K with drying.

Seasonal Variations in Exchangeable K under Field Conditions

Since exchangeable K increases with drying of some soils under laboratory conditions, it was thought that the same increases might occur under field conditions. If this were true, results of some K fertilizer studies in the field would be more readily understood.

To determine the variation in exchangeable K that occurred with drying under field conditions, the Aiken

(Ashton) soil was sampled by horizon at several sampling dates. Sampling began in the early spring of 1959 when the soil was wet and continued through the dry season. The final sampling date was after the soils were wet resulting from fall rains. Triplicate samples were taken at each date.

Exchangeable K content of field moist, air dried, 110°C oven dried and 200°C heated soils was determined using 1 N NH₄OAc, pH 7.0 extracting reagent. These data and soil moisture content data are given in Table 3. The tabled values are averages of triplicates.

Variation between the exchangeable K measured in triplicate samples was rather large. Therefore, these data could only be used to point out seasonal trends. The moisture content values, however, did not vary more than 3 per cent moisture between triplicate samples.

Results of this study indicated that the highest level of exchangeable K occurred when soils were at their lowest seasonal moisture content. The data indicate that as soils dry under field conditions, some K may be released causing an increase in exchangeable K. Then as soils are wetted by fall rains, some K is fixed resulting in a decrease in exchangeable K.

The fact that soil moisture content did not get below 11.7 per cent in any horizon during the dry season may be

Table 3. Seasonal variations in exchangeable K and moisture percentage of the Aiken soil under field conditions.

me K/100g

Horizon	3/26/59	5/28/59	6/18/59	8/5/59	9/16/59	1/9/60
Field moist						
Ap	0.18	0.16	0.19	0.26	0.18	0.20
B ₁	0.15	0.10	0.11	0.11	0.08	0.12
B ₂₁	0.08	0.08	0.09	0.08	0.06	0.09
B ₂₂	0.07	0.07	0.09	0.07	0.05	0.07
Air dried						
Ap	0.23	0.21	0.19	0.27	0.21	0.20
B ₁	0.18	0.22	0.13	0.14	0.09	0.13
B ₂₁	0.13	0.18	0.11	0.11	0.06	0.11
B ₂₂	0.13	0.18	0.12	0.11	0.06	0.11
110°C dried						
Ap	0.16	0.17	0.16	0.30	0.14	0.27
B ₁	0.14	0.11	0.12	0.17	0.10	0.18
B ₂₁	0.11	0.10	0.12	0.14	0.09	0.16
B ₂₂	0.10	0.08	0.11	0.14	0.11	0.15
200°C heated						
Ap	0.26	0.27	0.27	0.31	0.24	0.27
B ₁	0.24	0.22	0.22	0.20	0.18	0.21
B ₂₁	0.19	0.18	0.19	0.16	0.16	0.19
B ₂₂	0.19	0.17	0.19	0.16	0.15	0.18
Per cent soil moisture						
Ap	37.5	27.0	25.9	11.7	16.3	34.8
B ₁	37.5	27.7	29.9	21.8	21.1	35.1
B ₂₁	34.8	31.7	31.5	27.6	25.4	36.7
B ₂₂	31.7	30.5	29.5	28.4	27.6	36.2

the reason the data indicated only a trend. Greater increases in exchangeable K would likely be observed during a drier season.

Comparison of Extractants for Exchangeable K

It is generally accepted that NH₄ and K are fixed by layer silicates through the same mechanism. If these ions are fixed at the same sites by the same mechanism, they must compete for these sites when both are present. Because of this competition, it would appear that some K extractable with 1 N NH₄OAc may not be extractable with other reagents. Therefore, determining variations in exchangeable K with drying in NH₄OAc might be questionable. For this reason a comparison of the variations in exchangeable K with drying was made using 1 N NH₄OAc, pH 7.0 and 1 N NaOAc, pH 8.0.

Exchangeable K contents of all horizons of Tillamook, Dayton, Willamette, and two Aiken soils were determined using the two different extracting reagents. Field moist, 110°C oven dried, and 200°C heated soil samples were analyzed.

The data given in Table 4 show that the extractants varied in their efficiency for removal of K from soils. NH₄OAc removed more K from some soils while NaOAc removed more K from others.

Table 4. Variations in levels of exchangeable K measured by two extractants.

me K/100g

Series	Horizon	Field moist		110°C oven dried		200° heated	
		NH ₄ OAc	NaOAc	NH ₄ OAc	NaOAc	NH ₄ OAc	NaOAc
Aiken (Bonkowski)	A _p	0.29	0.22	0.32	0.29	0.34	0.34
	B ₁	0.15	0.12	0.17	0.21	0.23	0.25
	B ₂₁	0.16	0.08	0.18	0.18	0.22	0.29
	B ₂₂	0.11	0.10	0.16	0.17	0.22	0.19
Aiken (Ashton)	A _p	0.18	0.18	0.16	0.22	0.26	0.28
	B ₁	0.15	0.12	0.14	0.18	0.24	0.24
	B ₂₁	0.08	0.07	0.11	0.13	0.19	0.22
	B ₂₂	0.07	0.06	0.10	0.12	0.19	0.22
Willamette	A _p	2.00	2.14	1.95	1.41	1.93	1.62
	B ₁₁	1.81	1.96	1.60	1.19	1.58	1.44
	B ₁₂	1.25	1.44	1.21	0.78	1.12	0.55
	B ₂	1.34	1.47	1.29	0.72	1.26	0.84
	C	0.71	0.67	0.81	0.69	0.82	0.82
Dayton	A ₁₁	0.42	0.28	0.30	0.37	0.23	0.37
	A ₁₂	0.28	0.26	0.29	0.37	0.33	0.37
	A ₂	0.15	0.11	0.18	0.28	0.20	0.30
	B ₂₁	0.07	0.03	0.46	0.42	0.65	0.59
	B ₂₂	0.08	0.03	0.45	0.29	0.58	0.51
	C	0.05	0.01	0.39	0.27	0.53	0.43
Tillamook	A _p	0.23	0.18	0.27	0.25	0.29	0.27
	A ₁₂	0.20	0.16	0.25	0.25	0.28	0.29
	B ₁	0.15	0.14	0.18	0.20	0.22	0.22
	B ₂	0.11	0.11	0.14	0.14	0.16	0.16

In cases such as Aiken (Bonkowski) B₁ and B₂₁ and Dayton A₁₂ and A₂ horizons, where small increases in exchangeable K were measured in NH₄OAc with 110°C oven drying, larger increases were measured in NaOAc. Small decreases in exchangeable K were measured in NaOAc in the upper 4 Willamette horizons. Larger decreases were measured in NaOAc for these same soils. This indicated that where small increases in exchangeable K were measured in NH₄OAc, larger increases would be measured in NaOAc, and similarly where small decreases occurred, larger changes were found with NaOAc. These relationships did not hold for all soils, however, because both extractants showed small increases in exchangeable K of approximately equal magnitude with oven drying Tillamook horizon samples.

Sizeable and about equal increases in exchangeable K with drying were measured by both extractants in the Dayton B₂₁, B₂₂ and C horizons. Also, small decreases were measured in NH₄OAc in Willamette Ap, B₁₁, B₁₂ and B₂ horizons with oven drying, whereas large decreases were measured in NaOAc.

Results of this study indicated that changes in exchangeable K levels of soils with drying occurred with both extracting reagents. The magnitude of these changes varied with soils and extracting reagents used, but in cases where sizeable increases in exchangeable K were measured, both

extractants gave similar results. Therefore, increases in exchangeable K were real and not a result of using NH_4OAc extractant.

Increases and Decreases in Exchangeable K During Laboratory Wetting and Drying Cycles

Since both increases in exchangeable K with drying and wet fixation of K occur, and since the literature (49, 81, 83) indicated that Al plays an important role in K fixation and release, it seemed pertinent to obtain some detailed data under controlled wetting and drying in the laboratory. This study was initiated to obtain some information on the effect of temperature and added Al on the changes in exchangeable K which result from wetting and drying soils. It was also planned to obtain more information on the effect of wetting and drying without additional treatment.

Duplicate 4 gram soil samples dried at 110°C from 10 horizons of various soil series were weighed into polyethylene centrifuge tubes for each treatment in this study. Treatments consisted of various wetting and drying cycles, two temperatures and AlCl_3 treatments. Exchangeable K was determined in a 1 N NaOAc, pH 8.0, extract after each treatment. A series of treatments with each treatment in the series being preceded by the previous treatments was set up at room temperature and run concurrently as follows:

A. Exchangeable K was determined on the 110°C oven dry samples for comparison with exchangeable K levels after other treatments.

B. Samples were saturated with water and stored for 8 hours and then analyzed.

C. Samples were wetted, stored for 8 hours, dried, and analyzed.

D. Samples were wetted, stored for 8 hours, dried, rewetted for 60 hours and analyzed.

E. Samples were wetted for 8 hours, dried, rewetted for 60 hours, dried, and analyzed.

F. Samples were wetted and maintained moist for 16 days and then analyzed.

Another group of samples were treated the same except that the initial wetting in treatment B was made by a solution containing AlCl_3 so that 0.5 milliequivalents of Al per gram of soil was added. All treatments, including untreated and Al treated samples, were repeated at a temperature of 50°C.

Since temperature had no effect upon fixation or release of K, results of 25°C data will be discussed in detail. Conclusions from the data would be the same for both temperatures used (Table 5).

After an 8 hour moist storage period, only slight changes in exchangeable K were observed in soils not treated

Table 5. Increases and decreases in exchangeable K resulting from wetting and drying cycles¹ at two temperatures and two levels of AlCl₃ application.²

me K/100g

Series	Horizon	Original soils	Moist				Moist for 16 days
			110°C dried	8 hours	Dried	60 hours	
No added AlCl ₃ . At 25°C							
Cascade	Ap	0.18	0.18	0.13	0.09	0.13	0.12
	B ₂	0.30	0.30	0.28	0.21	0.27	0.22
Walla Walla	AC ₂	1.29	1.30	1.36	1.21	1.30	1.30
Nehalem	Alp	0.52	0.41	0.41	0.42	0.51	0.42
Chehalis	A ₁	0.51	0.51	0.50	0.37	0.48	0.39
Amity	B ₂₁	0.45	0.42	0.41	0.36	0.41	0.27
Dayton	B ₂₂	0.32	0.18	0.28	0.15	0.25	0.10
"	C	0.38	0.20	0.30	0.14	0.26	0.10
Willamette	Ap	1.88	1.86	2.02	1.78	1.89	1.71
Aiken (Ashton)	Ap	0.27	0.27	0.23	0.21	0.27	0.20
0.5 me/gram added AlCl ₃ . At 25°C							
Cascade	Ap	0.18	0.21	0.12	0.13	0.18	0.10
	B ₂	0.30	0.34	0.34	0.21	0.31	0.23
Walla Walla	AC ₂	1.29	1.30	1.31	1.25	1.32	1.30
Nehalem	Alp	0.52	0.60	0.50	0.39	0.49	0.44
Chehalis	A ₁	0.51	0.51	0.48	0.38	0.47	0.43
Amity	B ₂₁	0.45	0.46	0.45	0.36	0.45	0.45
Dayton	B ₂₂	0.33	0.39	0.37	0.32	0.41	0.33
"	C	0.38	0.39	0.35	0.28	0.38	0.33
Willamette	Ap	1.88	1.88	1.96	1.80	1.92	1.76
Aiken (Ashton)	Ap	0.27	0.29	0.24	0.22	0.24	0.20

¹Each cycle treatment was preceded by those listed to the left of it except the 16 day moist storage treatment. See pages 47 and 48.

²Tabled data are averages of duplicate determinations. Variation between duplicates in all cases was less than 3 per cent of the average value.

Table 5. Increases and decreases in exchangeable K resulting from wetting and drying cycles at two temperatures and two levels of AlCl_3 application. (Cont'd)

me K/100g

Series	Horizon	Original soils		Moist 8 hours		Moist 60 hours		Moist for 16 days
		110°C dried	Dried	Dried	60 hours	Dried	Dried	
No added AlCl_3 . At 50°C.								
Cascade	Ap	0.18	0.19	0.11	0.11	0.12	0.11	
	B ₂	0.30	0.30	0.24	0.17	0.27	0.19	
Walla Walla	AC ₂	1.29	1.28	1.18	1.14	1.26	1.22	
Nehalem	A _{1p}	0.52	0.56	0.41	0.42	0.48	0.46	
Chehalis	A ₁	0.51	0.51	0.42	0.36	0.44	0.40	
Amity	B ₂₁	0.45	0.42	0.33	0.24	0.33	0.22	
Dayton	B ₂₂	0.33	0.19	0.19	0.09	0.22	0.08	
	C	0.38	0.21	0.19	0.10	0.26	0.09	
Willamette	Ap	1.88	1.86	1.76	1.68	1.88	1.78	
Aiken (Ashton)	Ap	0.27	0.28	0.20	0.20	0.25	0.24	
0.5 me/gram added AlCl_3 . At 50°C.								
Cascade	Ap	0.18	0.18	0.11	0.14	0.12	0.13	
	B ₂	0.30	0.31	0.23	0.22	0.26	0.22	
Walla Walla	AC ₂	1.29	1.30	1.17	1.32	1.29	1.29	
Nehalem	A _{1p}	0.52	0.55	0.40	0.44	0.46	0.42	
Chehalis	A ₁	0.51	0.51	0.41	0.44	0.45	0.38	
Amity	B ₂₁	0.45	0.54	0.38	0.44	0.44	0.44	
Dayton	B ₂₂	0.33	0.42	0.33	0.37	0.42	0.32	
	C	0.38	0.40	0.31	0.35	0.38	0.29	
Willamette	Ap	1.88	2.05	1.70	1.93	1.85	1.81	
Aiken (Ashton)	Ap	0.27	0.30	0.20	0.24	0.24	0.20	

with AlCl_3 except Dayton B₂₂ and C horizons, which exhibited marked decreases in exchangeable K. With AlCl_3 treated samples, increases in exchangeable K occurred with all samples except the Willamette Ap. These increases were generally very small.

Upon drying after the 8 hour moist storage, Walla Walla AC₂, Dayton B₂₂ and C, and Willamette Ap samples gave increases in exchangeable K when no AlCl_3 was added. Of these samples only Walla Walla AC₂ and Willamette Ap gave increases in AlCl_3 treated samples, and these increases were relatively small. It should be remembered that these two soils both contained high initial levels of exchangeable K. Exchangeable K decreased upon drying after the 8 hour moist storage in all other samples.

In all samples, except the Cascade Ap, Nehalem Alp and Walla Walla AC₂, both AlCl_3 treated and untreated, exchangeable K levels were lower after 60 hours moist storage than after the first wetting and drying cycle. Therefore, fixation of K did occur under moist conditions, and it apparently took place after 8 hours and before 60 hours. Then, when samples were dried following this 60 hour moist storage period, increases in exchangeable K occurred with all samples of both AlCl_3 treated and untreated soil. The data indicated that moist fixation does occur with all of these soils and that this fixation might possibly be

reversed upon drying to bring about K release.

All treated and untreated samples stored for 16 days under moist conditions fixed K except Dayton B₂₂ and Walla Walla AC₂ treated with AlCl₃, which showed no change in K level. Again this indicates that moist fixation of K does occur.

Dayton B₂₂ and C horizons showed the greatest fluctuations of exchangeable K of the soils used. These results are in agreement with the findings from field sampling studies, in which greatest fluctuations were found in lower horizons of the Dayton.

Additions of AlCl₃ had different effects on different soils. These treatments greatly decreased the magnitude of variations in Dayton B₂₂ and C horizons. The opposite effect was found for the cases of Cascade Ap and B₁, Nehalem A_{1p}, and Amity B₂₁ horizons where additions of AlCl₃ increased the magnitude of the changes. Nevertheless, this study indicated that Al may play an important role in K fixation and release in soils.

Laboratory Wetting and Drying Cycle Studies With Standard Minerals

Results obtained in studies of changes in levels of exchangeable K with drying of various soils indicated that Al played an important role in K fixation and release by

soils. The following laboratory studies were designed to determine the effects of Al on changes in exchangeable K using standard conditions of alternate wetting and drying. Standard layer silicates pretreated to fix K and untreated were used to determine the effects of initial levels of K. Standard layer silicates were ground to less than 100 mesh for all studies.

Wetting and drying untreated layer silicates.

It is generally believed that changes in exchangeable K which occur with drying of soils are associated with the type of layer silicates present. Results obtained from studies of changes in exchangeable K which occur with wetting and drying of various soils were not detailed enough to show a definite relationship between layer silicate clays present and changes in exchangeable K levels. The following study was designed to determine the effects of wetting and drying on changes in exchangeable K levels of standard minerals.

Duplicate 2 gram samples were weighed into 50 milliliter polyethylene centrifuge tubes for each treatment. The treatments were: a) to analyze immediately, b) to analyze after 72 hours moist storage, and c) to analyze after 2 wetting and drying cycles in which the moist storage periods were 72 hours. Samples for X-ray analysis were cycled through the two wetting and drying cycles and again ground

to less than 100 mesh.

Results of this study given in Table 6 showed that K fixation occurred during moist storage and that increases in exchangeable K or K release occurred upon drying for all minerals except the vermiculites. The quantity of wet fixation was greatest for biotite 33 which fixed 2.01 milliequivalents of K per 100 grams. Also, biotite gave the largest K release upon drying which was 1.82 milliequivalents per 100 grams.

Table 6. Changes in exchangeable K during wetting and drying of untreated layer silicates.

me K/100g

Layer silicate ¹	Orig-inal level	After 72 hours wet storage	After two wetting and dry-ing cycles	Changes during wet storage ²	Changes upon drying ³
Mont. 24	0.83	0.70	0.83	-0.13	0.13
Mont. 21	0.56	0.41	0.56	-0.15	0.15
Illite 35	1.95	1.63	1.73	-0.32	0.10
Biotite 33	13.49	11.48	13.30	-2.01	1.82
Prochlor-ite 6	0.13	0.10	0.13	-0.03	0.03
Verm. 1	4.80	1.73	1.41	-3.07	-0.32
Verm. 2	9.14	2.38	1.41	-6.76	-0.97
Verm. 3	9.40	2.38	2.37	-7.02	-0.01
Verm. 4	5.82	1.65	0.96	-1.08	-0.59
Verm. 5	5.75	2.30	1.92	-3.45	-0.38
Verm. 6	2.69	1.61	1.02	-1.08	-0.59

¹See Materials and Methods section for identification of standard layer silicates.

²Column 3 minus column 2.

³Column 4 minus column 3.

All 6 vermiculites fixed K during moist storage and then fixed additional small amounts of K upon drying. It is important to remember that these vermiculites all definitely or possibly contained mica impurities.

Results of this study indicate that soils containing montmorillonoids, illite, especially biotite, and even prochlorite, either as single minerals or mixtures, might exhibit wet fixation of K and release of K upon drying. But, in soils containing vermiculite, either alone or with other minerals, only K fixation would be observed until the vermiculite had been converted to a mica. This mica then may give increases in exchangeable K upon drying and show wet fixation of K.

X-ray diffraction patterns of samples cycled through the 2 wetting and drying cycles were the same as those from the original materials. The K fixed by the vermiculites was insufficient to alter the X-ray diffraction patterns.

Drying Al saturated layer silicates in the presence of CaCl_2

Coleman¹⁰ found that drying Al saturated Utah bentonite in the presence of the neutral salt, CaCl_2 , that Ca became the exchangeable ion, Cl_2^- was given off and Al could not be recovered in NH_4OAc extracts. This resulted

¹⁰Personal communication, N. T. Coleman, Department of Soils, North Carolina State College, Raleigh, North Carolina. (Through M. E. Harward)

in a hypothesis developed by M. E. Harward and the author that exchangeable Al formed a precipitate during drying, and that formation of this precipitate might release fixed K by forcing the lattices of mica minerals to expand. The following study was done to determine whether or not K was released from Al saturated mica type minerals when they were dried in the presence of CaCl_2 .

Duplicate samples of illite 35 and biotite 33 were Al saturated by washing twice with 1 N AlCl_3 , followed by two distilled water washings to remove excess salt. These washings were done by shaking and centrifuging as previously discussed in the Methods and Materials section. CaCl_2 was added at a rate of 1 milliequivalent Ca per 1 gram of mineral. The samples were dried at room temperature followed by 2 hours drying in an oven at 40°C . Exchangeable K was determined in 1 N NaOAc, pH 8.0 extracts.

The treatments resulted in the release of 3.22 and 0.83 milliequivalents K per 100 grams from biotite and illite, respectively. This data are in agreement with the formulated hypothesis. However, no alteration of X-ray diffraction patterns were found resulting from this K release. This is not surprising since only very small amounts of clay mineral conversion could account for these quantities of K release.

Fixation of Exchangeable K

To gain a better understanding of K fixation and to determine which minerals would fix exchangeable K, the following study was initiated.

Quadruplicate 2 gram samples of all minerals, except vermiculites 2, 3, 4, 5, and 6, were weighed into 50 milliliter polyethylene centrifuge tubes and washed twice with 1 N KCl. Excess salt was removed with two distilled water washings. One group of duplicate samples was analyzed immediately for exchangeable K by extracting with 1 N NaOAc, pH 8.0 extracting reagent. Another group of duplicate samples was dried at room temperature and then at 40°C for two hours. These samples were then analyzed for exchangeable K.

The results given in Table 7 show that all layer silicates studied fixed K from exchangeable K upon drying. Montmorillonite 21 fixed considerably more than other minerals used, and illite 35, biotite 33, and prochlorite 6 fixed very little K.

X-ray diffraction analysis indicated a collapse of the lattice layers of the montmorillonites from their typical 15.8 Å spacings to broad peaks with maxima corresponding to a spacing of 12.6 Å as illustrated in Figures 1 and 2. The very intense 14.7 Å peak typical for vermiculite 1 completely disappeared and the 10 Å peak was

Table 7. Fixation of exchangeable K upon drying of standard layer silicates.

me K/100g

Layer silicate minerals	Exchangeable K after K saturation	after drying	K fixed
Mont. 24	88.87	84.71	4.16
Mont. 21	88.87	81.20	7.67
Illite 35	13.04	13.04	0.00
Biotite 33	12.01	11.57	0.45
Prochlorite 6	2.75	2.49	0.26
Verm. 1	57.54	53.86	3.68

greatly intensified as shown in Figure 3. This indicated that vermiculite 1 was almost completely converted to biotite.

The quantity of K fixation upon drying vermiculite 1 was not high enough to account for much mineral conversion. Yet, X-ray diffraction patterns indicated nearly complete conversion. This is not surprising since vermiculite 1 was shown to fix K under moist conditions. Therefore, most of the K which caused mineral conversion was probably fixed during the KCl washings. This was also probably true for the montmorillonites.

X-ray diffraction patterns for other minerals were not altered in this study.

Additions of K to Al saturated layer silicates

It was hypothesized that Al possibly had two roles in K fixation and release. Under certain conditions, Al

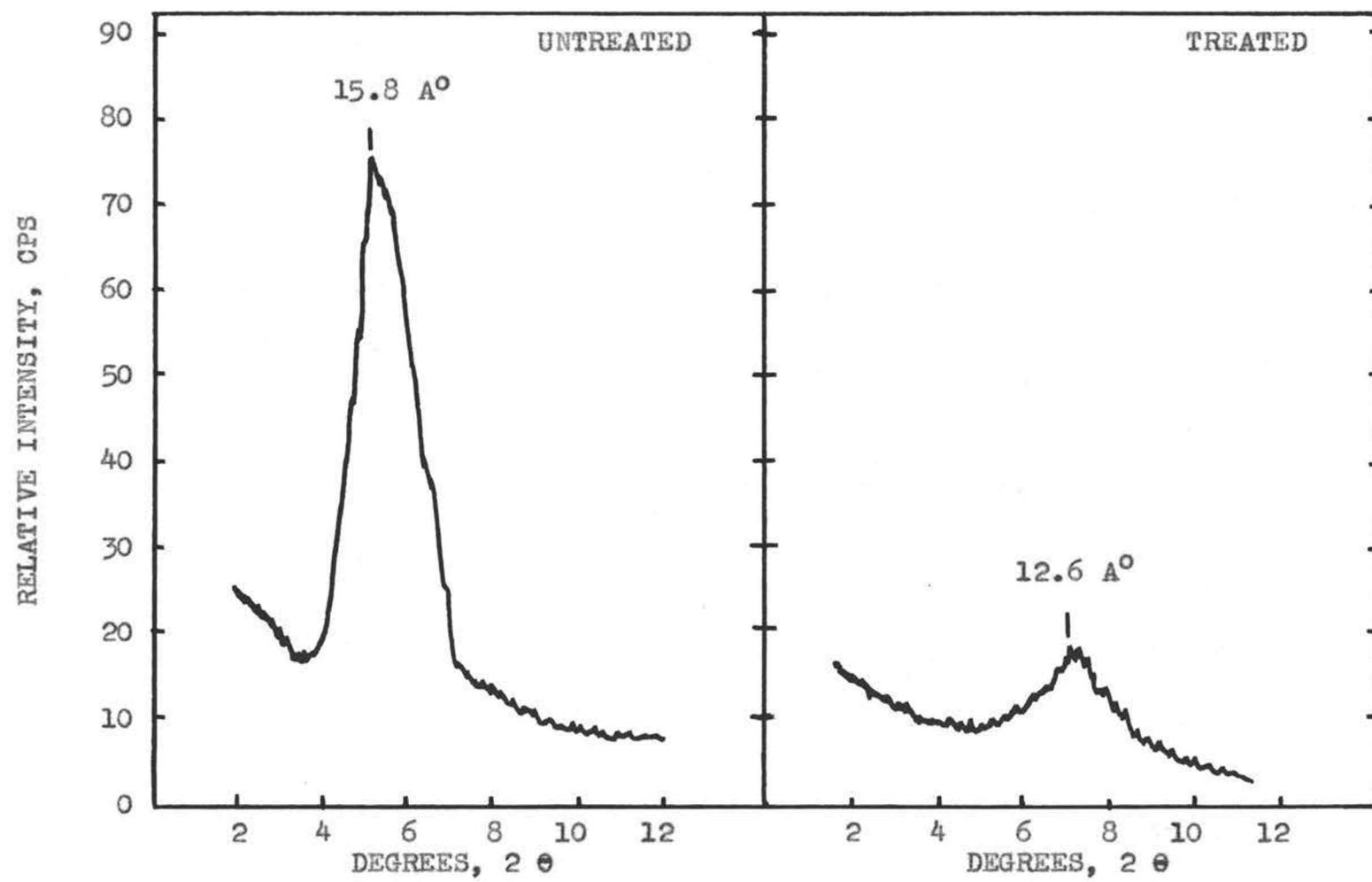


Figure 1. X-ray diffraction patterns for montmorillonite 24 for untreated samples and samples dried in the presence of exchangeable K.

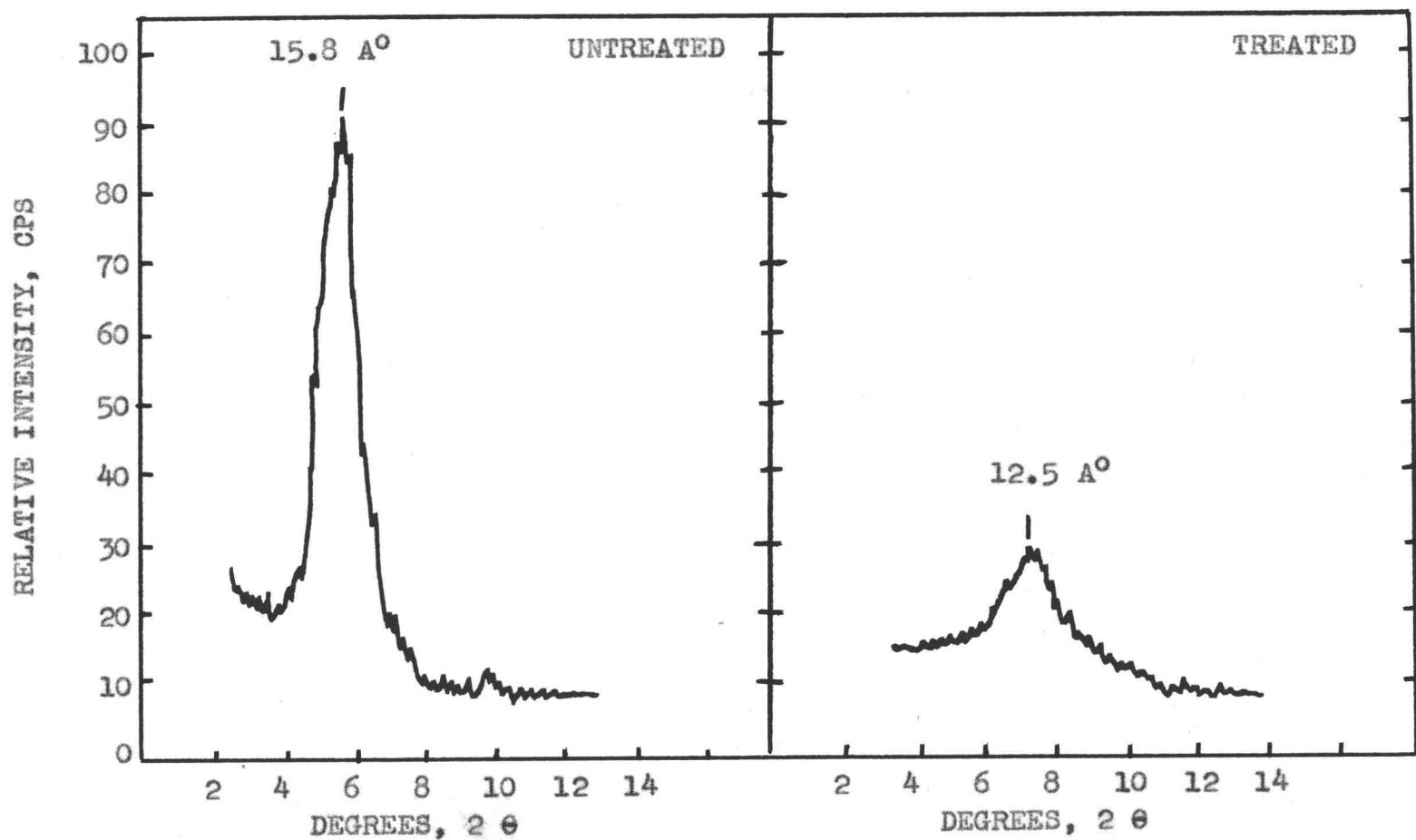


Figure 2. X-ray diffraction patterns for montmorillonite 21 for untreated samples, and samples dried in the presence of exchangeable K.

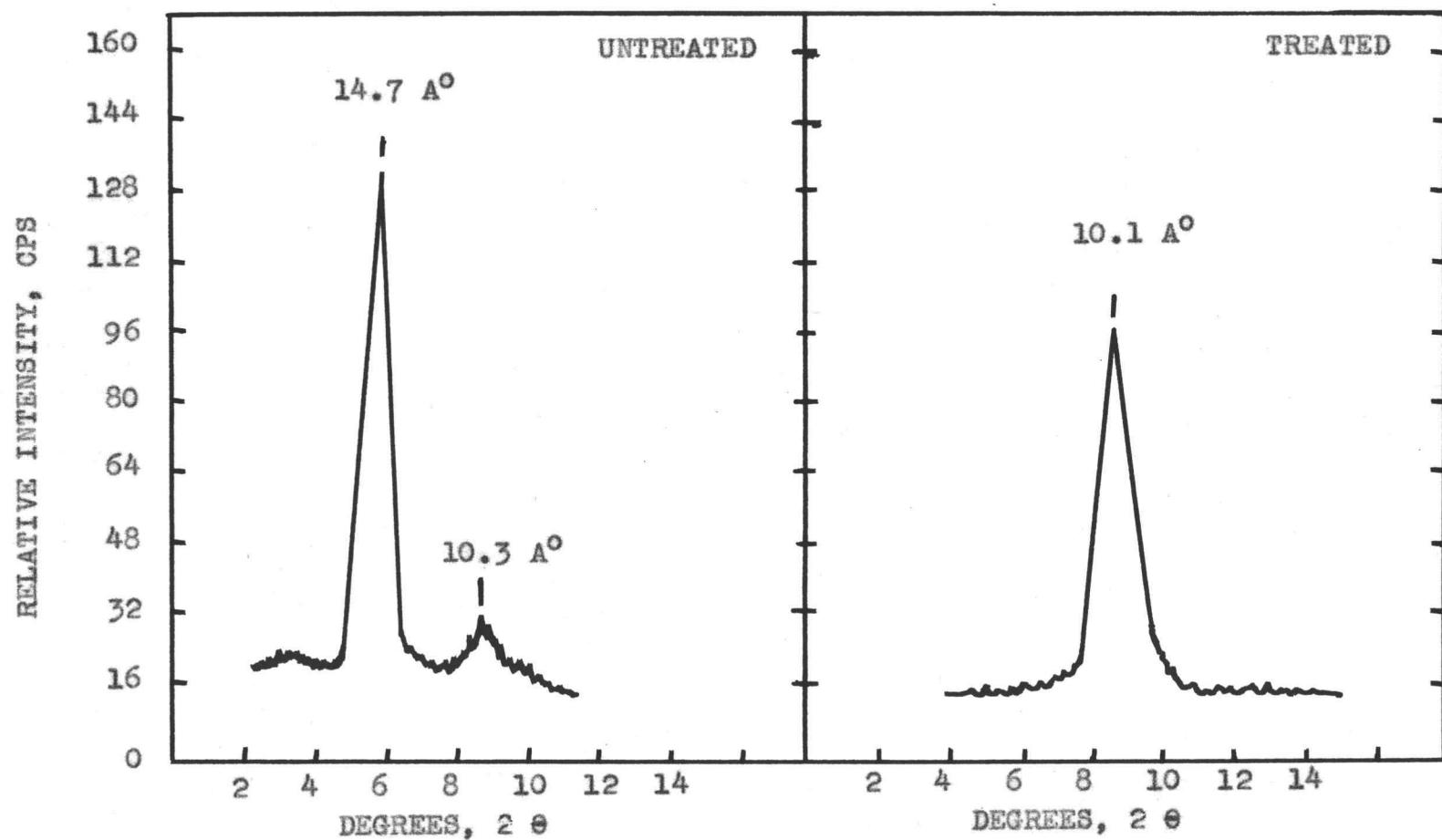


Figure 3. X-ray diffraction patterns for vermiculite 1 for untreated samples and samples dried in the presence of exchangeable K.

might bring about release of fixed K and under other conditions, Al may cause increases in K fixation. The following study was outlined to determine the effect of Al saturation on the fixation of added K with drying.

Quadruplicate 2 gram samples of montmorillonites 24 and 21, illite 35 and vermiculite 1 were Al saturated by two washings with 1 N AlCl_3 . Excess salt was washed out with two distilled water washings. KCl was added at a rate of 100 milliequivalents per 100 grams and the samples were dried at room temperature followed by drying at 40°C for two hours. Duplicate samples were extracted with 1 N CaCl_2 and 1 N NaOAc, pH 8.0 extractants, and the K removed was determined.

The data are given in Table 8. All minerals fixed considerable quantities of K, and all minerals fixed more K against CaCl_2 than against NaOAc extraction.

The data show that no Al was found in extracts from either extracting reagent. Therefore, the Al that was once exchangeable must have precipitated because mass action of either extractant would have removed any exchangeable Al present. It is very possible that some Al precipitate formed in interlayer positions blocking collapse of montmorillonite lattices as evidenced by the 12.5 \AA peaks (Figure 4). Figure 5 shows that a 12.5 \AA peak was also found in vermiculite 1 following these treatments. This

Table 8. Fixation of K against CaCl_2 and NaOAc of Al saturated layer silicates.

me K/100g

Layer silicate mineral	K added	K after drying		K fixed against		Presence of Al in extract	
		CaCl_2	NaOAc	CaCl_2	NaOAc	CaCl_2	NaOAc
Mont. 24	100	64.58	70.97	35.42	29.03	None	None
Mont. 21	100	71.61	78.00	28.39	22.00	None	None
Illite 35	100	81.84	90.97	18.16	9.21	None	None
Verm. 1	100	78.00	92.71	22.00	7.29	None	None

interlayer Al could also block removal of K from interlayer spaces by forming near the crystal edges effectively sealing K between uncollapsed lattice layers. This K would be measured as fixed K by the procedure used, but it would be fixed by a different mechanism than the conventional concept where trapping results from lattice collapse.

It was recognized that K might be fixed or occluded in Al precipitates. This possibility was tested by precipitating hydrated Al oxide in the presence of K. The data in Table 9 indicate that no K fixation resulted by formation of this precipitate.

Adding Al to K layer silicate systems

A hypothesis was formulated that Al ions might replace fixed K causing K release resulting in increases in exchangeable K. The following study was done to test

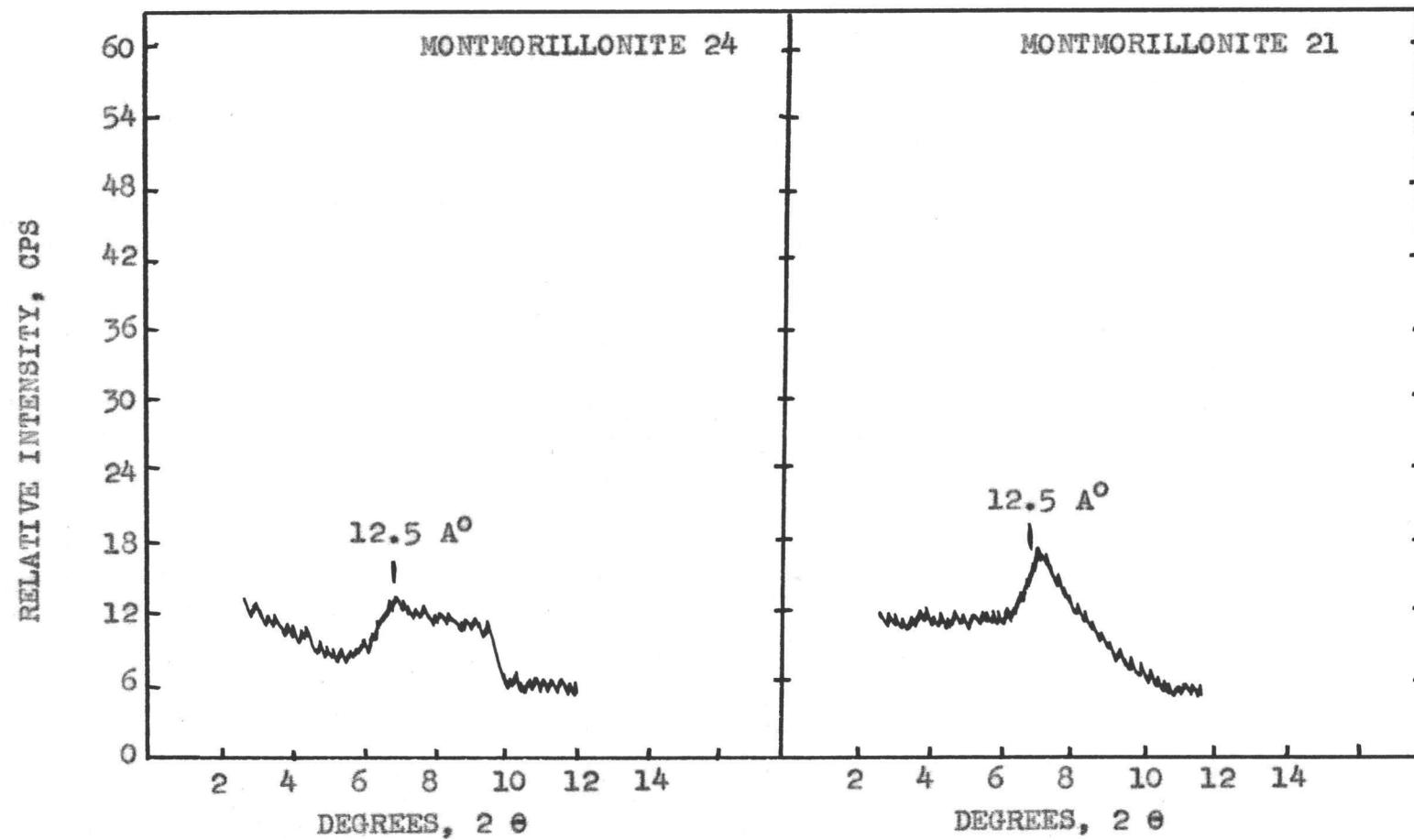


Figure 4. X-ray diffraction patterns for montmorillonites 24 and 21 after drying Al saturated samples in the presence of K.

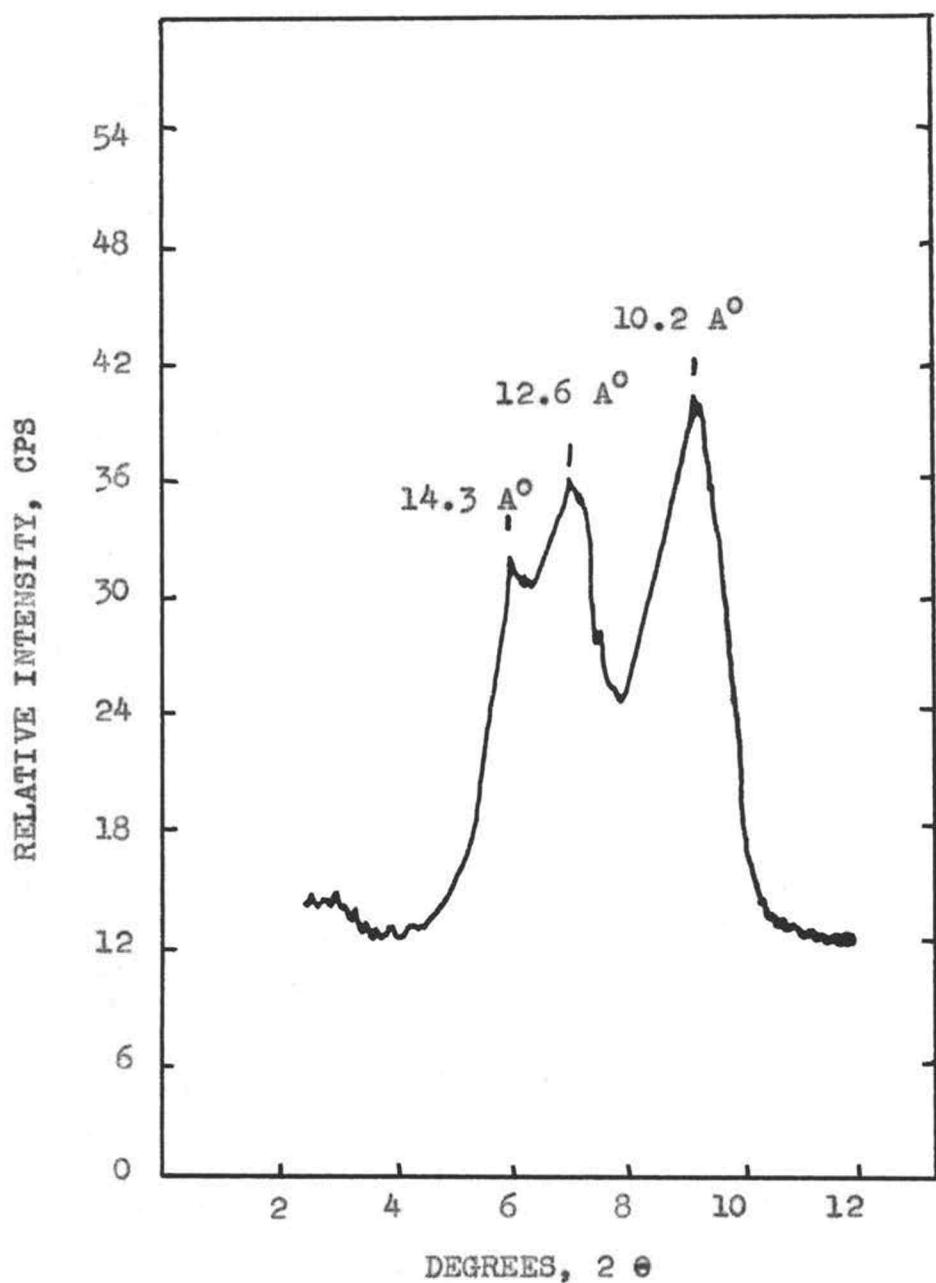


Figure 5. X-ray diffraction patterns for vermiculite 1 after drying an Al saturated sample in the presence of K.

Table 9. Precipitation of hydrated Al oxide in the presence of K.

Al used	K added	Soluble K	Exchangeable K	Fixed K
50	2.34	2.33	0.02	None
50	1.13	1.12	0.01	None
50	0.47	0.46	0.01	None

this hypothesis.

Samples of montmorillonites 24 and 21 and illite 35 were dried in the presence of excess K to bring about K fixation. These samples were washed three times with distilled water, dried and ground to less than 100 mesh. These materials and untreated illite 35 and biotite 33 were used for this study.

Duplicate samples of each mineral were analyzed for exchangeable K by extracting with 1 N NaOAc, pH 8.0 extractant. Analyses were made on untreated samples, samples stored under moist conditions for 72 hours, and samples dried after the 72 hour moist storage. The drying procedure was the same as described in the previous section. Another group of samples was treated with 1 milliequivalent of AlCl_3 per gram and analyzed at the three stages given for samples receiving no AlCl_3 .

The data in Table 10 showed that addition of Al resulted in the release of 16 milliequivalents per 100 grams

Table 10. Changes in exchangeable K in K layer silicate systems with added AlCl_3 and wetting and drying.

Clay	Initial	me K/100g			
		After 72 hours moist	During moist storage	With ² drying	
No Al added					
Mont. 24, K-fixed	63.94	63.94	63.61	0.00	-0.33
Mont. 21, K-fixed	76.09	75.77	74.49	-0.32	-1.28
Illite 35, K-fixed	24.62	24.62	24.94	0.00	0.32
Illite 35	2.56	2.56	2.56	0.00	0.00
Biotite 33	12.07	13.10	13.43	1.03	0.33
¹ me Al/g added					
Mont. 24, K-fixed	63.94	63.94	63.30	0.00	-0.64
Mont. 21, K-fixed	75.77	76.09	74.81	0.32	-1.28
Illite 35, K-fixed	25.90	25.26	25.26	-0.64	0.00
Illite 35	2.56	2.56	2.56	0.00	0.00
Biotite 33	14.39	31.32	31.32	16.93	0.00

¹ Column 3 minus column 2.

² Column 4 minus column 3.

from biotite 33 over the release found in the samples receiving no Al. Changes in exchangeable K levels of other minerals were small for both AlCl_3 treated and untreated samples.

X-ray diffraction patterns of the biotite 33 after release of 16 milliequivalents of K revealed only a 10 \AA° peak. This was the same as the pattern from the untreated material as shown in Figure 6. Therefore, Al ions probably replace fixed K resulting in K release. These Al ions probably remain in interlayer positions and the lattice remains collapsed.

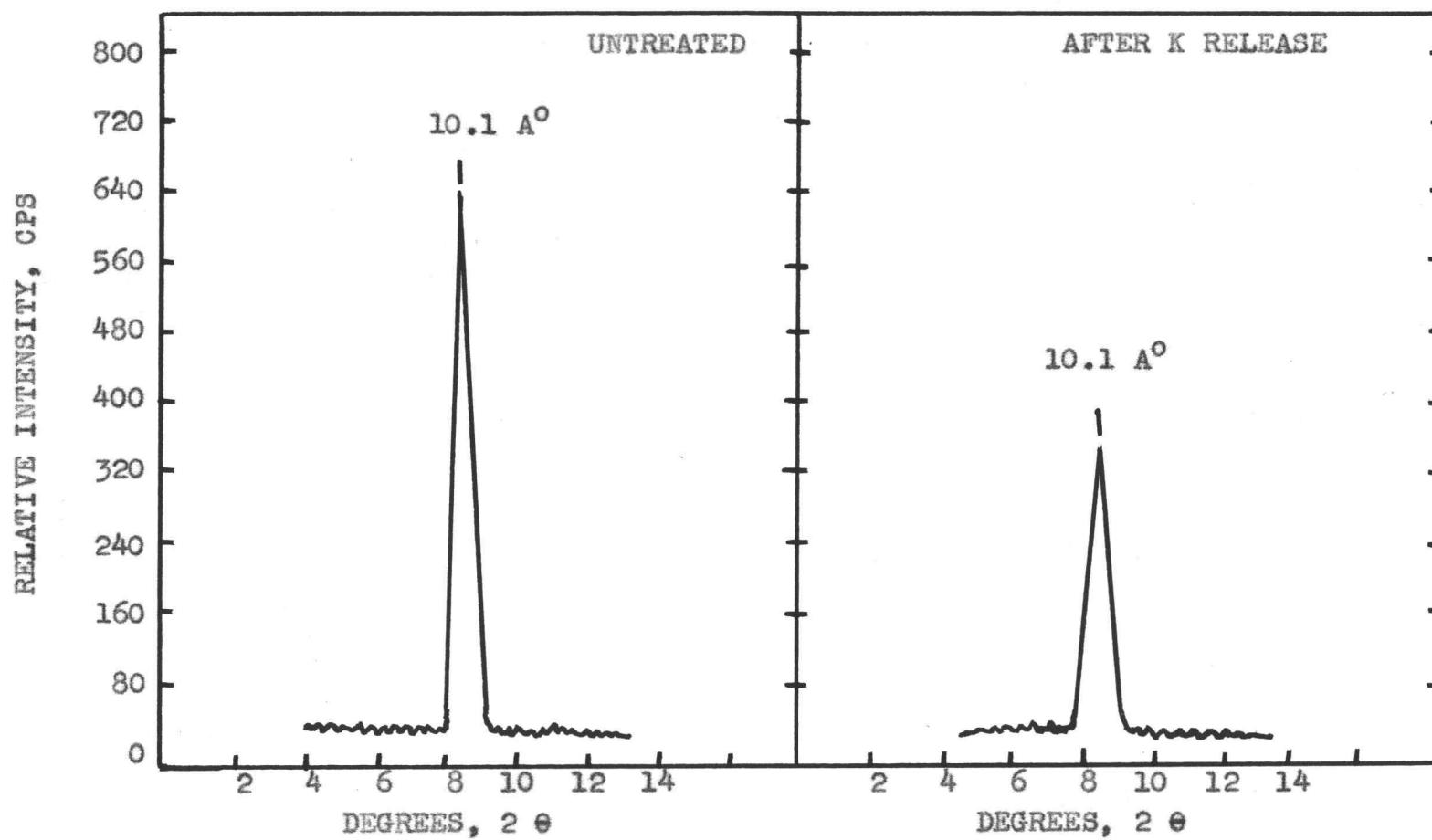


Figure 6. X-ray diffraction patterns for biotite 33 for untreated samples, and samples dried in the presence of Al.

GENERAL DISCUSSION

Changes in Exchangeable K upon Wetting and Drying of Soils

As seen from the data Oregon soils fix K, some release K and the K level in others does not change upon drying. These findings were expected and are consistent with findings of Attoe (4), Hanway and Scott (34, 35), Luebs (56), Luebs, Stanford and Scott (57) and other research workers. In general, these changes are not large in terms of milliequivalents, but often changes of 0.1 milliequivalents per 100 grams are found. Changes this size are equivalent to approximately 80 pounds of K per acre furrow slice which would be important from the soil fertility standpoint even though they seem rather insignificant in the laboratory.

The data indicated no definite relationship between the types of layer silicate clay minerals present and the type of change in exchangeable K which occurs when soils are dried. Yet, these results indicate that K is fixed by layer silicates and released from layer silicates.

Untreated samples of montmorillonite, illite, biotite and even prochlorite, to a lesser extent, fixed K under moist conditions and then released K upon drying. It appears therefore that soils containing any one or a combination of these clays might also fix K under moist conditions and release it upon drying. It is also probable

that soils containing one or more of these clays might fix added K since both montmorillonites and illite fixed added K.

Vermiculites used in this study, which are in reality vermiculite-mica mixtures, fixed K very rapidly under moist conditions and then fixed additional K upon drying. A soil containing vermiculite alone or as a major component of the layer silicates would probably exhibit only K fixation and no K release upon drying until enough conversion to mica had occurred to reverse the reaction.

Mechanisms of K Fixation

There may be several mechanisms responsible for K fixation by clay minerals. Certainly vermiculite fixes K by collapse of the lattice thus trapping K ions in interlayer positions, as evidenced by conversion of the typical 14 Å vermiculite peak to a 10 Å peak upon K fixation. All vermiculites of this study fixed K, and with one of them, where sufficient K was added, the conversion of the 14 Å peak to a 10 Å peak was complete. These results are consistent with findings of other researchers (11, 20, 22, 51, 69).

One possible mechanism postulated in this work is as follows: When K is added to Al montmorillonites and vermiculite, K fixation occurs, but the mineral lattices do

not collapse to 10 \AA° after wetting and drying. Extracting reagents do not remove Al from these Al saturated clays. Necessarily, the Al must go somewhere. It is concluded that this Al probably forms some precipitate in interlayer positions preventing lattice collapse to 10 \AA° . Very likely, this Al precipitate does not occupy all the interlayer space, but forms near crystal edges preventing removal of K by extractants. This would explain K fixation by minerals without collapse to 12.5 \AA° instead of by the conventional collapse to 10 \AA° as was observed in this study.

Mechanisms of K Release upon Drying

There are several possible mechanisms to explain certain amounts of K release upon drying. Grim (32) points out that Al moves from structural positions in the crystal lattice to exchangeable positions upon drying. If Al comes out of the lattice upon drying, a certain amount of degradation of clay minerals takes place. This might result in a slight amount of K release. This type of release is really no different than what is called K release resulting from weathering.

Since Al moves from the mineral lattice to exchangeable positions upon drying, and since after drying Al is not removed by either CaCl_2 or NaOAc extracting reagents it seems very likely that Al moves to interlayer positions in

clays rather readily. Furthermore, additions of Al to soils which released previously large amounts of K upon drying and re-fixed large amounts of K upon rewetting greatly suppressed wet fixation of K and increased K release. In order for Al to bring about these results, it must compete with K for interlayer exchange sites. Direct evidence for this competition of Al with fixed K is that additions of Al to biotite resulted in large increases in exchangeable K.

The literature also contains evidence of competition of Al for fixed K. Stanford (88) found that removal of Al and Fe from soils increased K fixation. He concluded that these ions competed with K for fixation sites or interlayer exchange positions. Scott, Ahlrichs and Stanford (83) found that the K-fixation capacity sharply decreased at pH levels where Al precipitates formed. This was felt to be a result of competition of Al precipitates with K for interlayer exchange sites. Rich and Obenshain (81) found that removal of an Al interlayer material by NH₄F resulted in the formation of a 10 Å peak upon K saturation whereas samples without interlayer material removed would not collapse from 14.7 Å spacing. Klages and White (49) stated that Al ions on interlayer exchange sites prevented collapse of a 14 Å mineral to 10 Å.

It is conceivable that as soils are drying, Al moves

from the mineral lattice of layer silicates to interlayer exchange positions, replaces fixed K, and brings about an increase in exchangeable K upon drying. As soils are wetted, this Al may readily be precipitated, allowing K to again occupy the fixation sites. Thus, wet fixation of K could be explained. Then upon drying more Al moves from the crystal lattice positions and again removes fixed K, and the cycle repeats.

CONCLUSIONS

The conclusions made from this study are listed briefly in the following paragraphs. The order in which they are listed is not intended to reflect their possible importance.

A. Some Oregon soils released K upon drying resulting in increases in exchangeable K. Under laboratory conditions the magnitude of the changes varied from very small amounts to large amounts with various soils. In general, soils containing moderate or small initial levels of exchangeable K exhibit increases upon drying.

Usually, soils which released K upon drying fixed K during moist storage.

Some Oregon soils did not release K but just the opposite, fixed it upon drying. In general these soils contained high initial levels of exchangeable K.

B. Nearly all soils exhibited increases in water soluble K upon drying. However, the levels of soluble K were extremely low and the increases observed upon drying were considered to result from clay mineral degradation during drying.

C. Under laboratory conditions, all soils tested tended to fix K under moist conditions. Usually K was released upon drying following these moist storage periods.

Increases and decreases in exchangeable K during wetting and drying cycles were suppressed in some soils and enhanced in others by adding AlCl_3 .

D. Seasonal changes of exchangeable K in Aiken soil under field conditions were not very marked. The soil moisture content never fell below 12 per cent. There was a tendency for the maximum levels of exchangeable K to occur at the minimum seasonal moisture level.

E. Drying Al saturated layer silicate clays containing fixed K in the presence of CaCl_2 resulted in increases in exchangeable K. This was probably a result of Al replacing fixed K during the drying process.

F. Untreated montmorillonites, illite, biotite and prochlorite fixed K during moist storage and released K upon drying. The quantities of fixation were about equal to the quantities of release for each clay. Changes in biotite were largest.

Several vermiculites, which were really vermiculite-mica mixtures, fixed K during moist storage and then fixed more K upon drying.

G. Montmorillonites and vermiculite fixed K from exchangeable K. This resulted in a c-axis collapse of montmorillonites from 15.7 \AA° to 12.5 \AA° and a c-axis collapse from 14.7 \AA° to 10 \AA° for vermiculite. Since these layer silicates fixed K under moist conditions, considerable K

fixation probably took place during K saturation prior to drying.

H. Additions of K to Al saturated montmorillonites, illite, and vermiculite resulted in K fixation by all minerals. The formation of a 12.5 \AA c-axis spacing with both montmorillonites and vermiculite was thought to be a result of Al precipitate forming in interlayer positions blocking collapse of the minerals forming interlayer spaces from which K could not be removed by extracting reagents. This process was proposed as a separate mechanism for K fixation as distinct from the conventional concept of trapping by mineral lattice collapse.

I. Additions of Al to montmorillonites and illite pretreated to fix K and to natural illite and biotite resulted in very large releases of K from biotite without changing the X-ray diffraction pattern. Al had little effect upon the other minerals.

J. From this study it was proposed that the release of K, and therefore increases in exchangeable K, resulted from Al moving to interlayer positions of clay minerals and replacing fixed K during drying of soils.

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A P P E N D I X

APPENDIX

Profile Description of Soils Used

Aiken silty clay loam (Reddish Brown Lateritic Soil,
locally called Reddish Brown
Latosol.)

Location: NE 1/4, section 10, T. 14S, R. 1W. Bonkowski
farm, Linn County, Oregon.

Description by: E. G. Knox, July 26, 1957 in connection
with Oregon Agricultural Experiment Sta-
tion Project 331.

Profile samples collected by: G. L. Ashcroft, D. L. Carter,
Ray A. Cattani, A. A. Theisen,
and J. L. Young. July 22,
1958.

Site: Soil from basalt, 10% east slope.

<u>Horizon</u>	<u>Depth</u> (in.)	<u>Description</u>
Ap	0-6	Dark reddish brown (5YR 3.5/3) dry, dark reddish brown (5YR 3/2) moist; silty clay loam; weak, very fine sub-angular blocky structure; hard, plastic, and sticky; few, fine soft shot; abrupt, smooth lower boundary.
B ₁	6-15	Dark reddish brown (5YR 2.5/3) moist; silty clay; moderate, very fine sub-angular blocky breaking to moderate, very fine granular structure; slightly hard, friable, very plastic, very sticky, very thin nearly continuous clay flows; clear, smooth lower boundary.
B ₂₁	15-26	Dark reddish brown (4YR 3/4) moist; silty clay; weak, medium and fine sub-angular blocky breaking to moderate, very fine sub-angular blocky structure; friable, very plastic, and very sticky; thin, nearly continuous clay flows; clear, smooth lower boundary.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
B ₂₂	26-40	Dark reddish brown (4YR 3/4) moist; silty clay; moderate, coarse sub-angular blocky breaking to moderate, fine angular blocky structure; firm, very plastic, very sticky; common, large black MnO ₂ coatings; thin, continuous clay flows.

Aiken silty clay loam (Reddish Brown Lateritic Soil, locally called Reddish Brown Latosol)

Location: SE 1/4, of NE 1/4, section 3, T. 14S, R. 1W.
Ashton farm, Linn County, Oregon.

Description by: E. G. Knox, March 26, 1959 in connection with Oregon Agricultural Experiment Station Project 331.

Profile samples collected by: E. G. Knox, D. W. James, and D. L. Carter, March 26, 1959.

Site: Soil from basalt, 0-5% south slope.

<u>Horizon</u>	<u>Depth (in.)</u>	<u>Description</u>
A _p	0-7	7.5YR 4/4 dry, 7.5YR 3/3 moist; silty clay loam; weak, fine sub-angular blocky structure; friable, plastic, sticky; abrupt, smooth lower boundary.
B ₁	7-18	6YR 4/3 dry, 5YR 3/3 moist; silty clay loam or silty clay; moderate, medium, fine and very fine sub-angular blocky structure; friable, plastic, very sticky; very thin continuous clay skins on larger peds; clear, wavy lower boundary.
B ₂₁	18-31	4YR 4/4 dry, 4YR 3,5/4 moist; silty clay, weak, medium prismatic breaking to moderate, medium, sub-angular blocky structure; firm, plastic, very sticky; very thin continuous clay skins; clear, wavy lower boundary.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
B ₂₂	31-42	4YR 4/5 dry, 4YR 4/4 moist; silty clay; moderate coarse and medium sub-angular blocky structure; very firm and firm, plastic, sticky; common medium block MnO ₂ coatings; thin continuous clay skins.

Amity silt loam (Gray-Brown Podzolic or Prairie Soil)

Location: SW 1/4, SW 1/4, NW 1/4, section 6, T. 5S, R. 1W.
(Hole no. 75 as per J.Pomerening.)

Description by: J. Pomerening, Summer 1957; L. H. Robinson,
July 29, 1958.

Profile samples collected by: D. L. Carter, R. A. Cattani,
L. H. Robinson, and J. L. Young, July 29, 1958.

Site: Grass waste land, no slope, old alluvium.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A ₁	0-12	Very dark brown (10YR 2.2) silt loam; strong medium and fine granular structure; slightly sticky, slightly plastic; many roots and concretions.
A ₂	12-20	Very dark grayish brown (10YR 3/2) moist, with very dark gray (10YR 3/1) in worm holes and on some ped surfaces; silt loam; moderate, fine sub-angular blocky structure; very friable, slightly sticky, slightly plastic; many roots and worm holes; very many concretions (looks like mottling), smooth, clear boundary; pH 5.2.
B ₁	20-29	Dark grayish brown (2.5Y 4/2 moist, with common, fine and medium dark yellowish brown (10YR 4/4) mottles, also many concretions with brown streaks; silty clay, weak, medium sub-angular blocky into weak, very fine sub-angular blocky structure; very friable, slightly sticky, slightly plastic, porous and loose; many worm holes, roots, and concretions; smooth gradual boundary; pH 5.3.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
B ₂₁	29-37	Dark gray (2.5Y 4/1) moist, with 5 to 10 mm. chunks of dark brown (10YR 3/3) that are connected to one another between worm holes; large chunks of fragipan in lower 5"; silty clay; weak, medium and coarse sub-angular blocky into moderate, very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; loose and porous; one continuous network of worm holes; some concretions and toots; wavy clear boundary; pH 5.5.
C _m	37-41	Dark brown (10YR 3/2.5) and dark grayish brown (2.5Y 4/2) moist (50-50); silt loam; no structure; slightly sticky, slightly plastic; many worm holes with clay flows; few roots; mica conspicuous; pH 6.5; water at 50".

Cascade silt loam (Reddish Brown Lateritic soil with fragipan)

Location: NE 1/4, SW 1/4, section 1, T. 5N, R. 2W. Lloyd farm, Columbia County, Oregon, on alfalfa plots established by T. L. Jackson.

Description by: A. A. Theisen, June 10, 1958.

Profile samples collected by: B. L. McNeal, J. E. Yahner, D. L. Carter, and R. A. Cattani, July 1958.

Site: Cultivated field, on 10% west slope. Imperfectly drained; from loess over water-deposited silts.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
Ap	0-8	Dark yellowish brown (10YR 3/4) moist; silty loam; moderate, very fine sub-angular blocky to fine granular structure; friable, non-sticky, non-plastic; common, spherical concretions (shot); pH 5.4.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A ₃	8-18	Dark yellowish brown (10YR 4/4) moist; silt loam; weak, fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; few shot; pH 5.4.
B ₁	18-27	Yellowish brown (10YR 5/6) moist; silty clay loam with mottles; moderate, fine sub-angular blocky structure; friable, sticky, plastic; common black coating of manganese dioxide; pH 5.2.
B ₂	27-32	Dark yellowish brown (10YR 4/4) moist; silty clay loam with ped borders of light brownish gray; weak, very coarse prismatic structure; very firm; sticky, plastic; manganese dioxide coatings; pH 5.2.

Chehalis silt loam (Alluvial soil)

Location: NW 1/4, NE 1/2, section 36, T. 11S, R. 5W.
Horticulture farm, Linn County, Oregon.

Description by: J. Pomerening, July 30, 1958.

Profile samples collected by: D. L. Carter, J. Pomerening and B. L. McNeal, July 30, 1958.

Site: Maple, ash, poison oak; no slope; from post pleistocene alluvial mixture of igneous and sedimentary materials; well drained.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A ₁	0-11	Very dark brown (10YR 2/2) moist; silt loam; strong, fine and very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; numerous, fine (1-2 mm.) roots, several large (1-2") tree roots; numerous earthworm holes; clear, smooth horizon boundary.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A ₃	11-18	Very dark grayish brown (10YR 3/2) moist; silt loam; moderate, fine and very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; common fine roots and numerous worm holes; clear, smooth horizon boundary.
C ₁	18-28	Very dark grayish brown (10YR 3/2) moist on ped surface, dark grayish brown (10YR 4/2) in peds; silt loam; weak, medium sub-angular sticky, slightly plastic, common fine roots; numerous, fine worm holes, common, large vertical worm channels; clear, gradual horizon boundary.
C	28-48	Very dark grayish brown (10YR 3/2) moist on ped surface, dark grayish brown (10YR 4/2) in peds; silt loam; weak, very fine and fine sub-angular blocky structure; friable, slightly sticky, slightly plastic (very smooth); common, large (2-5 mm.) vertical worm holes; few, fine roots below 36".

Dayton silt loam (Planosol)

Location: SE 1/4, SE 1/4, SW 1/4, section 8, T. 13S, R. 4W, about 800 feet E of road intersection at Peoria, Linn County, Oregon about 60 feet N of the road.

Description by: E. G. Knox, May 21, 1959.

Profile samples collected by: E. G. Knox and J. L. Young, May 21, 1959.

Site: Abandoned field or pasture, with grass, rose and weeds; level, poorly drained, from old, silty, water deposited material (Willamette silts).

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A ₁₁	0-3	Dark gray (10YR 4/1) moist; silt loam with common, fine, distinct reddish mottles; moderate, very fine sub-angular blocky structure; friable, slightly plastic,

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
All (cont'd)		slightly sticky; abundant roots; common, fine interstitial pores; few dark concretions (2-4 mm.); lower boundary abrupt and smooth; pH 5.0.
A ₁₂	3-9	Dark gray (10 YR 4/1) moist; silt loam with common, medium, distinct reddish mottles; weak, fine sub-angular blocky structure; friable, slightly plastic, slightly sticky; common roots; few, fine tubular pores; few concretions (1-2 mm.); lower boundary abrupt and smooth; pH 5.0.
A ₂	9-18	Gray (10YR 5/1) moist; silt loam with common, medium, distinct mottles; weak, medium sub-angular blocky structure; friable, slightly plastic, slightly sticky; few roots; common fine and medium tubular pores; common concretions (1-2 mm.) with a concentration at the upper boundary; lower boundary abrupt and wavy; pH 5.0.
B ₂₁	18-30	Gray (2.5Y 5/1) moist; clay with few, faint, fine mottles; weak, very coarse prismatic breaking to weak, very fine angular blocky structure; very plastic, very sticky; very few roots; common, very fine tubular pores; common, thin clay skins; common, spherical black concretions; lower boundary diffuse and smooth; pH 5.4.
B ₂₂	30-40	Grayish brown (2.5Y 4.5/2) moist; clay or silty clay with common, fine, distinct mottles; weak, very coarse sub-angular blocky structure; very plastic, very sticky; few, very fine tubular pores; common, thin clay skins; common concretions (1-2 mm.); lower boundary diffuse and smooth; pH 6.6.
Deep	40-52	Olive brown (2-5Y 4/3) moist; silty clay loam with common, medium, distinct mottles; very weakly platy structure; firm, plastic, sticky; common, fine and very fine tubular pores; few, clay skins; common, small black coatings of manganese dioxide; pH 7.0.

Nehalem silt loam (Alluvial soil)

Location: NW 1/4, SW 1/4, section 5, T. 2S, R. 9W, SW corner of the enclosure of the Nehalem soil fertility plots established on the Tillamook Naval Air Base, Tillamook County, Oregon by T. L. Jackson, E. A. Jenne and others.

Description by: E. G. Knox, L. H. Robinson and C. Bowlsby, March 27, 1958.

Profile samples collected by: R. A. Cattani and L. H. Robinson, August 1958.

Site: Silt from recent silty alluvium on the flood plain of the Trask River. Well drained on less than 1% slope.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A _{lp}	0-9	Dark yellowish brown (10YR 3/4) moist, brown (10YR 5/3) dry; silt loam (but almost silty clay loam); strong, fine and very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; abundant roots; abundant, fine and very fine interstitial pores; lower boundary clear and smooth; pH 5.2.
A ₁₂	9-17	Dark yellowish brown (10YR 3.5/4) moist; silt loam (but almost silty clay loam); moderate medium prismatic breaking to strong, fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; abundant roots; abundant, fine tubular pores, few, medium and coarse tubular pores; coatings on peds and pores are dark yellowish brown (10YR 3/4); lower boundary, gradual and smooth; pH 5.4.
AC	17-36	Dark yellowish brown (10YR 3.5/4) moist; silty clay loam; moderate, coarse prismatic breaking to strong, medium sub-angular blocky structure, friable, plastic, sticky; common roots, abundant, fine tubular pores; lower boundary gradual and smooth; pH 5.6.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
C ₃	36-54	Dark yellowish brown (10YR 3.5/4) moist; silty clay loam; weak, coarse prismatic breaking to moderate, fine and medium sub-angular blocky structure; friable, plastic, sticky, few roots; abundant fine and very fine tubular pores, few, medium and coarse tubular pores, few faint fine mottles; pH 5.6.

Tillamook silt loam (Ando like)

Location: SW corner of the enclosure of the Tillamook soil fertility plots established on the Tillamook Naval Air Base, Tillamook County, Oregon by T. L. Jackson, E. A. Jenne and others.

Description by: E. G. Knox and L. H. Robinson, March 26, 1958.

Profile samples collected by: L. H. Robinson, R. A. Cattani August 1958.

Site: Soil from silty alluvium on a broad terrace above the present flood plain, well drained and level.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A _{1p}	0-7	Black (10YR 1.2) moist, silt loam, moderate fine and very fine sub-angular blocky structure, friable, slightly sticky, slightly plastic, abundant roots, abundant fine and very fine interstitial pores, lower boundary abrupt and smooth.
A ₁₂	7-16	Black (10YR 1/2) moist, silt loam, strong medium and fine sub-angular blocky structure friable, slightly plastic, slightly sticky, abundant roots, abundant fine and very fine interstitial pores, lower boundary clear and wavy.
A ₁₃	16-39	Black (10YR 1/2) moist, silt loam, weak coarse prismatic breaking to weak medium and fine sub-angular breaking to moderate very fine granular structure, friable, slightly plastic, slightly sticky, common

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A ₁₃ (cont'd)		roots, abundant fine and very fine tubular and interstitial pores, lower boundary clear and irregular.
B ₁	39-50	Very dark brown (10YR 2.5/3) moist, silty clay loam, moderate fine and very fine sub-angular blocky breaking to strong very fine granular structure, friable, plastic, sticky, few roots, abundant fine and very fine tubular pores, few medium and coarse tubular pores, lower boundary clear and irregular.
B ₂	50-60	Dark Yellowish brown (10YR 3/4) moist, silty clay loam, moderate medium to very fine sub-angular blocky structure, friable, plastic, sticky, few roots, abundant fine and very fine tubular pores, few medium and coarse tubular pores, few rounded pebbles.

Willamette silt loam (Prairie soil)

Location: NW 1/4, NW 1/4, NE 1/4, section 16, T. 13S, R. 4W; at an old farmstead about 1 1/2 miles E of Peoria, Linn County, Oregon.

Description by: E. G. Knox, May 21, 1959.

Profile samples collected by: E. G. Knox and J. L. Young, May 21, 1959.

Site: At edge of a cultivated field; level, well drained from old, silty, water-deposited material (Willamette silts).

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A _p	0-6	Very dark brown (10YR 2.5/2) moist; silt loam; strong, medium and fine sub-angular blocky structure; friable, plastic, slightly sticky; abundant roots; abundant, coarse to very fine tubular and interstitial pores; lower boundary abrupt and smooth; pH 5.6.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
B ₁₁	6-16	Very dark grayish brown (10YR 3/2) moist; silty clay loam with very dark brown coatings; moderate, medium and fine sub-angular blocky structure; friable, plastic, sticky; common roots; common, medium and coarse, and abundant, fine and very fine tubular pores between the ped; lower boundary clear and smooth; pH 6.0.
B ₁₂	16-39	Dark yellowish brown (10YR 3/4) moist; silty clay loam; moderate, medium sub-angular blocky breaking to weak, fine sub-angular blocky structure; friable, plastic, very sticky; common roots; abundant, fine and very fine tubular pores; abundant, thin clay skins (10YR 3/3); lower boundary clear and wavy; pH 5.8.
B ₂	30-46	Brown (10YR 4/3) moist; silty clay loam; moderate, coarse angular blocky structure; firm plastic, sticky; few roots; abundant, fine and very fine tubular pores; abundant clay skins (10YR 3/3); lower boundary diffuse and smooth; pH 5.6.
C	46-56	Brown (10YR 4/3) moist; silty clay loam; weak, very coarse sub-angular blocky structure; firm and friable, plastic, sticky; few roots; few, medium and common, fine tubular pores; few, thin clay skins on ped and few, thick skins in vertical pores; few manganese dioxide coatings; pH 6.0.

Walla Walla silt loam (Chestnut soil)

Location: Section 20, T. 1S, R. 17E; 2 1/2 mi. S & E of Moro.

Description by: L. H. Robinson, August 1958.

Profile samples collected by: L. H. Robinson, R. A. Cattani, Aug. 1958.

Site: Crested wheat grass, cheat and blue-bunch grass. Soil from loess, 8% NE slope, gently sloping upland, moderate permeability, well drained; semiarid climate, 13"/yr. moisture, 1800' elevation. Reduced iron around root channels, mycelia shaped lime along root channels.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u>
A _{lp}	0-7	Very dark grayish brown (10YR 3/2) moist; very fine sandy loam or loam; weak, medium platy structure; friable, slightly sticky, slightly plastic; abundant roots; abrupt, smooth lower boundary; pH 6.5.
A _{l2}	7-13	Very dark grayish brown (10YR 3/2) moist; very fine sandy loam or loam; weak, coarse prismatic structure; friable, slightly sticky, slightly plastic; abundant roots; abrupt, smooth lower boundary; pH 6.6.
AC	13-23	Dark brown (10YR 3.5/3) moist; silt loam; weak, coarse prismatic and weak, medium coarse sub-angular blocky structure; friable, slightly sticky, slightly plastic; plentiful roots; gradual, smooth lower boundary; pH 6.6.
AC ₂	23-47	Dark brown (10YR 4/3) moist; silt loam; same characteristics as AC except has many fine pores; pH 6.8.
C _{ca1}	47-57	Dark brown (10YR 4/3) moist; silt loam; massive structure; friable, slightly sticky, slightly plastic; many fine pores; coarse, sand-size basalt fragments; diffuse, smooth lower boundary; pH 8.3.
C _{ca2}	57	Dark brown (10YR 4/3) moist; silt loam; same characteristics as horizon above except pH 8.2.

Table 11. Relationships of Soils Used with Respect to Parent Material and Annual Rainfall.

Soils formed from:	12	Annual Rainfall (inches)			
		40	45	50	90
Recent silty aluvium		Chehalis			Nehalem
Water-deposited silts:					
well drained		Willamette			Tillamook
imperfectly drained		Amity			
poorly drained		Dayton			
Loess		Walla Walla		Cascade	
Residuum and colluvium from basalt			Aiken		

Table 12. Major Genetics Features of Soils.

Soil Series	Great Soil Group	Major Genetic Features
Aiken Amity	Reddish Brown Latosol Prairie soil	low base saturation, textural B, dark colored A textural B, dark colored A, mottles and gray color, moderate base saturation
Cascade		fragipan, "shot" in A, dark colored A, textural B
Chehalis Dayton	Alluvial soil Planosol	none strong textural B with abrupt upper boundary gray colors, moderate base saturation
Nehalem	Alluvial soil	none
Tillamook	Ando soil	very thick, dark A, very low base saturation, probable high allophane content
Walla Walla Willamette	Chestnut soil Prairie soil	dark colored A horizon, high base saturation dark colored A, textural B, moderate base saturation

Table 13. Characterization of Soils Used.

Soil	Horizon	Depth Inches	Organic ¹ Matter %	Mechanical Analysis ²			CEC ³ me/100g	Ex.Ca, ² Mg, K, & Na me/100g	Moisture Air Dry %	pH 1:1
				Clay %	Silt %	Sand %				
Aiken (Bonkowski)	Ap	0-6	6.11	63	28	9	23.9	9.4	4.3	5.3
	B ₁	6-15	4.33	66	26	8	24.0	9.3	4.6	5.4
	B ₂₁	15-26	2.82	70	23	7	21.4	8.8	4.5	5.2
	B ₂₂	26-40	0.94	75	20	5	19.8	8.1	4.6	5.3
	Deep	52-72	0.29	76	19	5	21.9	7.0	4.5	5.3
Aiken (Ashton)	Ap	0-7		51	37	12	27.4	3.6	5.3	5.5
	B ₁	7-18		55	33	12	27.7	4.0	5.6	5.6
	B ₂₁	18-31		66	25	9	23.9	2.5	5.6	5.3
	B ₂₂	31-42		64	27	9	24.3	2.3	5.5	5.4
Amity	A ₁	0-12	4.58	29	48	23	16.1	7.6	2.8	4.9
	A ₂	12-20	0.90	29	47	24	20.2	9.4	2.4	5.1

¹Walkley, A. and I. A. Black. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37:29-38. 1934.

²Kilmer, Victor J. and Lyle T. Alexander. Methods of making mechanical analyses of soils. Soil Science 68:15-24. 1949.

³Schollenberger, C. J. and R. H. Simon. Determination of exchange capacity and exchangeable bases in soils - ammonium acetate method. Soil Science 59:13-24. 1945.

Table 13. Characterization of Soils Used (Cont'd).

Soil	Horizon	Depth Inches	Organic Matter %	Mechanical Analysis			CEC me/100g	Ex.Ca, Mg, K, & Na me/100g	Moisture Air Dry %	pH 1:1
				Clay %	Silt %	Sand %				
Amity (cont)	B ₁	20-29	0.15	28	53	19	18.0	15.9	2.9	5.4
	B ₂₁	29-37	0.33	26	50	24	22.7	22.4	4.0	5.5
	C _m	37-41	0.19	23	39	38	22.8	22.8	4.0	5.7
	C	41+	0.19	20	55	25	23.9	25.3	4.2	6.1
Cascade	A _p	0-8	4.35	20	52	28	16.4	5.7	2.6	5.4
	A ₃	8-18	1.27	23	49	28	11.6	4.7	2.6	5.4
	B ₁	18-27	0.31	21	55	24	11.6	6.3	2.3	4.9
	B ₂	27+	0.17	23	56	21	15.0	12.0	2.7	5.0
Chehalis	A ₁	0-11	6.65	35	62	3	38.7	32.3	4.5	5.8
	A ₃	11-18	2.03	32	62	6	31.2	26.8	4.5	6.0
	C ₁	18-30	1.70	30	57	13	29.0	26.1	4.4	6.1
	C	28+	1.38	27	60	13	28.1	26.1	4.2	5.9
Dayton	A ₁₁	0-3	6.60	19	78	3	16.1	7.5	2.0	4.8
	A ₁₂	3-9	2.16	21	76	3	12.7	6.0	1.7	4.9
	A ₂	9-18	0.70	25	72	3	12.6	7.7	1.8	5.0
	B ₂₁	18-30	0.70	52	47	1	33.7	28.0	5.3	5.2
	B ₂₂	30-40	0.40	43	54	3	33.5	31.5	5.4	5.9
	Deep	40+	0.32	28	69	3	28.6	28.2	4.5	6.4

Table 13. Characterization of Soils Used (Cont'd).

Soil	Horizon	Depth Inches	Organic Matter %	Mechanical Analysis			CEC me/100g	Ex.Ca, Mg, K, & Na me/100g	Moisture Air Dry %	pH 1:1
				Clay %	Silt %	Sand %				
Nehalem	A _{1p}	0-9	8.34	38	57	5	53.7	35.0	7.2	5.3
	A ₁₂	9-17	3.68	38	57	5	50.6	37.5	7.4	5.5
	AC	17-36	3.52	35	58	7	48.7	35.7	7.3	5.5
	C ₃	36-54	2.19	32	59	9	50.5	38.1	7.3	5.6
Tillamook	Ap	0-13	8.01	41	45	14	40.0	2.0	7.4	4.7
	A ₁₂	13-48	11.13	41	44	15	43.0	3.1	8.1	4.9
	B ₁	48-55	5.43	40	45	15	38.3	1.9	7.6	4.7
	B ₂	55+	2.36	35	43	22	39.5	2.3	7.6	4.9
Walla Walla	A _{1p}	0-7	1.97	13	46	41	12.4	11.2	1.6	6.6
	A ₁₂	7-13	0.94	12	44	44	11.7	10.6	1.4	6.6
	AC	13-23	0.46	14	56	30	12.3	11.5	1.6	7.0
	AC ₂	23-47	0.22	10	58	32	13.3	13.5	1.6	7.4
	C _{cal}	47-57	0.11	8	59	33	14.1	18.6	1.8	8.1
	C _{ca2}	57+	0.11	6	62	32	14.7	20.9	1.9	8.1
Willamette	Ap	0-6	6.56	27	71	2	22.9	22.3	2.3	5.2
	B ₁₁	6-16	2.53	28	70	2	17.6	14.0	1.9	5.6
	B ₁₂	16-30	1.20	27	69	4	15.1	11.8	1.9	5.5
	B ₂	30-46	0.29	33	64	3	25.8	21.5	3.9	5.7
	C	46-56	0.25	28	69	3	23.9	22.3	3.8	5.7