

AN ABSTRACT OF THE THESIS OF

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(Name of student) (Degree)

in Soils presented on Dec 20, 1974
(Major Department) (Date)

Title: THE POTASSIUM STATUS OF EASTERN AND CENTRAL
OREGON SOILS

Abstract approved: Redacted for privacy
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The potassium status of selected soils from central and eastern Oregon, that have shown a wide range in response from potassium was investigated. The silt and clay minerals were identified using X-ray crystallography. The potassium extracted by water, NH_4OAc , and HNO_3 was evaluated on the total soil and on the clay, silt and sand fractions.

A wide range in particle size of the soils included in this study was found, especially in the sand and silt fractions. The sand and silt fractions varied from 87 and 10%, respectively in the Quincy soil to 20 and 61%, respectively in the Nyssa soil.

The clay and silt fractions of the Deschutes, Poe and Henley soils were dominated by amorphous materials with minimum indication of other minerals. These soils represented the extremes in NH_4OAc and HNO_3 extractable potassium. The Deschutes soils had

196 and 643 $\mu\text{g}/\text{gm}$ of NH_4OAc and HNO_3 extractable potassium, respectively. The Poe soils averaged 484 and 1394 $\mu\text{g}/\text{gm}$ of NH_4OAc and HNO_3 extractable potassium, respectively, while the Henley soil, selected for its luxuriant supply of potassium, contained 1384 and 3449 $\mu\text{g}/\text{gm}$ of NH_4OAc and HNO_3 extractable potassium respectively.

In contrast, the Quincy, Ephrata, Metolius, Agency, Madras, and Nyssa soils contained no amorphous materials. In these soils, smectites and mica were the dominant minerals in the clay fraction and vermiculite, mica, and feldspars were the dominant minerals in the silt fraction. The NH_4OAc extractable potassium was 250 $\mu\text{g}/\text{gm}$ in the Quincy soil, 353 $\mu\text{g}/\text{gm}$ in the Ephrata soil, 305 $\mu\text{g}/\text{gm}$ in the Metolius soil, 427 $\mu\text{g}/\text{gm}$ in the Agency soil and 560 $\mu\text{g}/\text{gm}$ in the Nyssa soils, while the NH_4OAc averaged 476 $\mu\text{g}/\text{gm}$ in the Madras soils. The HNO_3 extractable potassium varied from 975 $\mu\text{g}/\text{gm}$ in the Metolius soil to 2232 $\mu\text{g}/\text{gm}$ in the Nyssa soil.

The NH_4OAc and HNO_3 extractable potassium extracted from any one group of soils, increased with the increase in clay and silt, and the decrease in sand. The exchangeable potassium associated with the clay fraction increased with the presence of smectites. The HNO_3 extractable potassium associated with the silt increased with the presence of mica, vermiculite, and potassium feldspar in this fraction.

The soils included in this study also represented a wide range in response from potassium. Marked potassium response was found on the Deschutes soils but not on the Poe and Henley soils with similar texture, sandy loam, and similar mineralogy, mostly amorphous materials. Response from potassium was also found on the Metolius, Agency and Madras (#10) soils but not on the Madras (#12 and 13) with similar texture and mineralogy. The Quincy, Ephrata and Nyssa soils, with similar mineral composition, have shown no response from potassium.

Critical potassium levels of about 440 $\mu\text{g}/\text{gm}$ for NH_4OAc or 1400 $\mu\text{g}/\text{gm}$ for HNO_3 could be established for all soils from central Oregon. However, when these critical levels are used on soils from other areas, the soils on which response from potassium might be measured, are not identified.

Separate critical potassium soil test values should be established for both NH_4OAc and HNO_3 when soils from different areas with marked differences in parent material, minerals present, texture, and potassium crop removal are evaluated for response from potassium. Potassium fertilization recommendations should be based primarily on the relationships between a soil test value and potassium response on field experiments on similar groups of soils for each crop.

The Potassium Status of Eastern and
Central Oregon Soils

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1975

APPROVED:

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Date thesis is presented

Dec 20, 1974

Typed by Ilene Anderton for Ahmed Ali Abuzkhar

ACKNOWLEDGEMENTS

The author is sincerely grateful for the encouragement and aid given by Dr. T. L. Jackson throughout this research and in the preparation of this thesis manuscript.

Similarly, the advice and constructive criticism in preparation of this thesis of Dr. V. V. Volk is greatly appreciated.

The author is indebted to Dr. M. E. Harward for assistance with the x-ray diffraction pattern interpretations.

Finally, to my wife, Kheria, for which my appreciation for her patience and understanding cannot be adequately expressed by words.

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THE POTASSIUM STATUS OF EASTERN AND CENTRAL OREGON SOILS

INTRODUCTION

Potassium is a major constituent of most soils, and, as an essential element, is present in substantial amounts in plants.

Potassium availability to plants is varied and related to chemistry, structure and texture of soil minerals.

The potassium available to plants exists, mainly, in two forms in mineral soils; readily and slowly available. Readily available potassium, a combination of water soluble and exchangeable potassium occurs in either soil solution or on exchange sites of the soil. The slowly available or nonexchangeable potassium, consists of potassium fixed between the internal surfaces of certain 2:1 types of clay minerals and potassium that is present as a structural constituent of soil minerals such as micas and feldspars.

Physical and chemical weathering, leaching and crop removal of potassium are factors that may cause transfer of potassium from the slowly to the readily available forms. However, heavy application of potassium fertilizers may cause reversion from readily to the slowly available forms, especially under conditions where micas and vermiculites are predominant in soils. Because of these different forces on the soil system, a dynamic equilibrium between the

different forms of potassium in soils exists.

Very frequently water soluble and exchangeable potassium have been used to evaluate the potassium status of soils. The amount of exchangeable potassium in soils has generally been positively correlated with potassium uptake by plants under both field and greenhouse conditions. Since some soils have large amounts of potassium that cannot be extracted by ordinary extraction procedure, a boiling HNO_3 extracting method to measure slowly available potassium has been developed. The difference in the amount of potassium extracted by IN HNO_3 and exchangeable potassium has generally been referred to as the slowly available (nonexchangeable) potassium. Significant correlations between the amount of slowly available potassium and potassium uptake by plants have been reported in some instances.

A wide range in response from potassium on potatoes in central and eastern Oregon soils has been reported. This study, therefore, was undertaken to develop a better understanding of the distribution of exchangeable and slowly available potassium in soils where response from potassium has been evaluated, and to study the distribution of these two forms of potassium associated with the sand, silt, and clay fractions.

Perhaps the type of minerals present exerts the greatest influence on potassium reactions in soils and its availability to plants.

It was felt, therefore, identification of minerals present in the clay and silt fractions of these soils developed under arid conditions would help to understand some of the differences in their potassium supplying capacity.

OBJECTIVES

The objectives of this study were:

- 1) To investigate the potassium status of selected soils from central and eastern Oregon.
- 2) To investigate the release of potassium from these soils using different extracting solutions.
- 3) To determine the availability of potassium associated with the sand, silt, and clay fractions of these soils.
- 4) To study the relationship between potassium supplying power of these soils and clay minerals present.

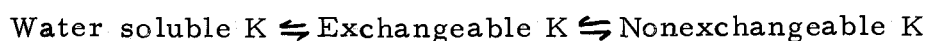
REVIEW OF LITERATURE

Potassium is an essential nutrient and thus is present in all plants and productive soils (McLean and Simon, 1958; Mortland, 1958). Marked differences in the availability of soil potassium to plants exists between soils. The potassium nutrition of plants may depend on the rate at which the available potassium is released from the soil rather than the total potassium present in the soil (McLean and Simon, 1958; Oliveira et al., 1971; Conyers and McLean, 1969).

The various forms of potassium in soils can be classified on the basis of availability to plants into three general groups: (1) unavailable; (2) readily available; and (3) slowly available. The greatest portion (90-98 percent) of all soil potassium occurs in the relatively unavailable form (Attoe and Truog, 1945). The minerals which contain most of this potassium are the feldspars and the micas. The readily available potassium constitutes only about 1-2 percent of the total potassium in an average mineral soil (Attoe and Truog, 1945). The readily available potassium exists in soils in two forms: (1) in the soil solution, and (2) absorbed on the soil colloidal surfaces. The slowly available potassium comprises the potassium present in the crystal structure of soil minerals (De Mumbrum, 1959; Ellis and Mortland, 1959; Mortland, 1958) and/or the potassium fixed between the sheets of some 2:1 type clay minerals. The potassium

fixation process is due to the collapse that takes place in the lattice upon drying (De Mumbrum, 1959; Wear and White 1951; Legy and Axley, 1959). The slowly available potassium cannot be replaced by ordinary exchange methods and consequently is referred to as non-exchangeable potassium.

An equilibrium between the different forms of potassium in soils has been represented (Peach and Bradfield, 1943; Reitemeier, 1951) by the equation:



This dynamic equilibrium has a highly significant value from the practical standpoint. Uptake of solution potassium by plants results in a temporary disruption of the equilibrium. To restore the balance, some exchangeable potassium moves into the soil solution, and some non-exchangeable or fixed potassium reverts into the exchangeable form until the equilibrium is again established. On the other hand, when water-soluble fertilizers are added, just the reverse of the above adjustment occurs.

Potassium Release From Soil Minerals

Clay mineralogy has often been related to potassium supplying power of soils, with hydrous micas or illite serving as a principle source of potassium supply (Cook and Hutchinson, 1960). In a

greenhouse experiment conducted in Nebraska, the uptake of non-exchangeable potassium by alfalfa from soil surface layers was more closely related ($r = 0.85$) to hydrous mica of the fine silt ($20-2\mu$) than to K-bearing minerals provided by other separates (Abed Fawzi et al., 1966).

The total potassium released from K-bearing minerals using H-resin and boiling nitric acid (HNO_3) was found (McClellan and Brydon, 1964) in the order of feldspar < illite < muscovite < biotite. Wentworth and Rossi (1972) studied the uptake of potassium from layer silicates by barley and observed the following sequence for potassium release:

vermiculite > illite > biotite > phlogopite > muscovite.

In a study of potassium uptake by grain sorghum, Hipp and Thomas (1967) reported the uptake of solution potassium and exchangeable potassium was extremely fast for the kaolinitic soil relative to the montmorillonitic soil.

The effect of wetting and drying treatments on release and fixation of potassium by some Kentucky soils as related to clay mineralogy has been studied extensively (Dowdy and Hutcheson, 1963; Cook and Hutcheson, 1960). Hydrous mica appeared to be the source of potassium released by drying, whereas fixation at moisture levels higher than 4% was associated with vermiculite and fixation at lower

moisture levels with montmorillonite. Stanford (1948) found that montmorillonite did not fix potassium until the soil was dried. He also observed that H, Fe and Al would prevent fixation of potassium by hydrous mica in acid soils under moist conditions. However, potassium fixation by hydrous mica was noted when calcareous soils were dried.

Cook and Hutcheson (1960) have shown that the 14 Å vermiculite spacing exhibited by soils of high potassium supplying power easily collapsed to 10 Å after K-saturation and a heat treatment. On the other hand, soils of lower potassium supplying power were essentially not affected by K-saturation and required a higher heat treatment before the x-ray spacing collapsed to 10 Å. Potassium removal from biotite by leaching with dilute NaCl and also by intensive cropping transformed biotite to vermiculite (Mortland, 1958). Barshad (1954) has stated that hydrous mica converts to vermiculite upon the release of potassium and that vermiculite then developed major importance in potassium fixation. While some of the particles (250-50 μ) still showed the vermiculite band around the edge of unweathered biotite, the smaller particles (50-2 μ) were completely weathered to vermiculite (Mortland, 1958).

Potassium Release as a Function of Particle Size

The release of potassium from different size fractions of the

soil has been studied by several workers. However, a definite relationship between potassium release and particle size has not been established.

Smith et al. (1971) have suggested that each soil has its own potassium release characteristics, that is dependent upon the particle size distribution and minerals present. Their suggestion was based on theoretical equations and special potassium release models. The differences in the potassium released from various fractions of soil clays were clearly shown by an increased potassium release with increased particle size (Doll et al., 1965). This was the case even though the fine fractions contained relatively high potassium levels. On the other hand, Scott (1968) studied the release of potassium as affected by particle size in mica and found that initially the release of potassium increased as the particle size decreased. When essentially all the potassium had exchanged, the rate of potassium release slowed down.

The amount of non-exchangeable potassium in the soil fractions prepared without destruction of organic matter (Maclean et al., 1963) decreased with increasing particle size. Smith et al. (1968) also reported an increase in potassium exchange with a decrease in particle size. The maximum amount of the exchangeable potassium was in the $< 2\mu$ fraction.

The potassium content of the soils of various regions in related

to the parent material and the degree of weathering. In 30 Rhodesian soils, the highest potassium content occurred in the sand fraction (2-0.02 mm) of 17 samples and decreased with particle size (Salmon, 1964). While the highest potassium content was in the silt fraction (0.02-0.002 mm) in 11 samples, it was only in two samples in the coarse clay fraction (0.002-0.0005 mm). In some soils of Ghana the total potassium content varied from 0.11 to 1.02% and was related ($r = 0.70$) to silt but not clay or sand (Acquaye et al., 1967). The potassium reserve of some Nigerian soils correlated positively ($r = 0.85$) with the sand content but was negatively correlated ($r = -0.73$) with the clay content (Igbo, 1972). These results are in contrast to those reported (Armond, 1962; Maclean and Brydon, 1963) for soils of temperate regions, where the total potassium values were of considerably greater magnitude (0.86 - 4.5%). The highest potassium level was observed in the finer fractions (> 0.002 mm).

Potassium Extraction From Soils

The use and efficiency of different potassium extracting solutions has been studied by many workers to evaluate the potassium supplying power of soils.

Conyers and McLean (1969) reported that potassium extracted by ammonium acetate, HNO_3 , HCl , and sodium tetraphenylboron from soils prior to cropping generally correlated better with

potassium uptake than did potassium extracted by magnesium acetate, HClO_4 -HF, and water. However ammonium acetate was the best of all ($r = 0.92$) in alfalfa and HCl ($r = 0.82$) in millet. Potassium removed from some Mississippi soils by sunflower plants correlated well with HCl ($r = 0.953$), ammonium acetate ($r = 0.949$), and NH_4Cl ($r = 0.930$) extractable potassium. Potassium extracted by HNO_3 and distilled water did not correlate well with the sunflower growth (Nelson, 1959).

In western Oregon soils the total potassium in the HNO_3 extract (exchangeable + non-exchangeable potassium) and potassium released from non-exchangeable forms by HNO_3 (total HNO_3 extractable K - ammonium acetate extractable K) appeared to be better indexes ($r = 0.959$, $r = 0.937$) than ammonium acetate extractable potassium ($r = 0.852$) for the potassium removed by clover under greenhouse conditions (Pope and Cheney, 1957). Exchangeable and non-exchangeable potassium should be used as availability indexes (Nuttal et al., 1967). However, Nash (1971) stated that the standard ammonium acetate method is the most practical one for predicting the uptake of potassium ($r = 0.973$).

Olivera et al. (1971) studied the potassium removed from southern Brazilian soils by exhaustive cropping and chemical extraction methods. Potassium exchanged by ammonium acetate and potassium removed by boiling HNO_3 correlated highly

($r = 0.744$ and 0.881 , respectively) with ryegrass uptake, however, all extractants greatly underestimated actual plant-available potassium under intensive cropping.

In summary, the relationship between potassium release and clay minerals suggests that hydrous mica and micaceous minerals are the most probably seats of potassium in soils. The isomorphous substitution of Al for Si and the nature and size of the holes between two adjacent tetrahedral layers provides an exchange site able to hold potassium in micaceous minerals.

The amount of potassium that can be extracted by using various extracting methods depends mainly on the strength, size, and valency of the replacing cation as well as pH of the extractant.

While there is no universal agreement, most research work reported suggests a higher potassium release with smaller particle sizes. Methods used to separate particle size fractions as well as mineralogy of soil appeared to influence the release of potassium.

Most research workers evaluating relationships between potassium response and extractable potassium have used ammonium acetate as the extracting agent. However, in some cases other extracting agents have been found to be superior in predicting potassium response and potassium supplying power of some soils.

MATERIALS AND METHODS

Soil samples were collected from 15 locations where fertilizer experiments had been established on potatoes to evaluate response from nitrogen, phosphorous, and potassium. The samples for this study were collected from the surface 12 inches, air dried, ground, and sieved through a 2 mm sieve. The location, soil series, soil pH, CEC, and exchangeable bases for each soil is presented in Table 1. A brief morphological description of these soils is presented in Appendix I.

Cation Exchange Capacity Determination

Ammonium Acetate Method

A soil sample (10 gm) was weighed into an extracting bottle and 1 N ammonium acetate pH 7 (50 ml) was added. The sample was shaken for 30 minutes, filtered through a Buchner funnel fitted with a Whatman No. 42 filter paper, and leached with 1N ammonium acetate pH 7 (150 ml). The excess ammonium acetate was washed out with 150 to 200 ml of ethyl alcohol (95%). The ammonium saturated soil was extracted with 0.1 N HCl (250 ml), the filtrate transferred to a 300 ml Kjeldahl flask, and NaCl (10 gm), 40% NaOH (30 ml), and an anti-bumping disc added. The sample solution

Table 1. Location, soil series, pH, CEC, and exchangeable bases of the soils studied.

Group	Soil #	Location	Soil Series	Soil pH		CEC		Exchangeable bases			
				H ₂ O	KCl	Ammonium acetate	Strontium chloride	K	Ca	Mg	Na
				me/100 gm							
1	1	Boardman area	Quincy	6.60	5.76	7.56	7.97	0.77	5.0	1.1	0.56
	2	Hermiston	Ephrata	6.31	5.65	8.41	9.10	0.35	5.6	1.8	0.26
	X			6.46	5.71	7.99	8.54	0.56	6.3	1.45	0.41
2	3	Powell Butte	Deschutes	6.53	5.75	12.28	12.86	0.28	7.3	3.6	0.46
	4	Terrebone	Deschutes	6.51	5.53	10.13	10.93	0.56	3.6	2.6	0.21
	X			6.52	5.64	11.21	11.90	0.42	5.45	3.10	0.34
3	5	Midland Klamath	Poe	5.77	4.90	12.00	12.90	0.82	7.6	3.4	0.26
	6	S.E. of K. Falls	Poe	5.77	4.90	11.03	12.17	1.01	6.3	2.5	0.19
	7	Malin area	Poe	5.91	5.07	14.15	15.90	1.79	7.0	3.0	0.19
	8	W. of Merrill	Henley	6.80	6.40	24.90	25.73	3.21	15.3	4.3	1.51
	X			6.06	5.32	15.52	16.68	1.71	9.05	3.30	0.54
4	9	Metolius	Metolius	5.82	5.05	16.43	17.61	0.71	7.6	4.8	0.24
	10	N.W. of Madras	Madras	5.50	4.65	18.35	19.10	0.96	7.8	4.5	0.24
	11	N.W. of Madras	Agency	5.71	4.90	17.71	19.70	0.90	8.0	4.6	0.24
	12	Madras airport	Madras	6.12	5.67	19.39	20.54	0.71	11.9	5.1	0.38
	13	N.W. of Madras	Madras	6.03	5.26	18.26	19.79	1.34	8.5	4.5	0.49
	X			5.84	5.11	18.03	19.35	0.92	8.76	4.70	0.32
5	14	S.E. of Ontario	Nyssa	6.44	5.80	27.90	30.23	1.13	16.1	6.9	0.71
	15	S.E. of Ontario	Nyssa	6.30	5.76	27.03	29.19	1.78	14.8	6.0	0.63
	X			6.37	5.78	27.47	29.71	1.46	15.45	6.45	0.67

was distilled into a 500 ml Erlenmeyer receiving flask which contained saturated boric acid (50 ml) and three drops of mixed indicator. The NH_3 distillate was titrated with 0.10 N HCl and NH_4^+ content calculated (Schollenberger and Simon, 1945).

Strontium Chloride Method

An air dried soil (3 gm) was weighed into a 50 ml centrifuge tube, and 1N strontium chloride (30 ml) was added. The sample tube was shaken for 10 minutes, centrifuged, and the supernatant discarded. The strontium saturation procedure was repeated two times. The excess strontium chloride was washed from the soil sample with three 95% ethylalcohol wash treatments, (30 ml each). Strontium was extracted from the soil by addition of 0.1 N HCl (30 ml). The sample was shaken for 10 minutes, centrifuged until clear, and the supernatant decanted into a 100 ml volumetric flask. The extraction procedure was repeated two times. The extract was diluted to volume with 0.1 N HCl. The strontium content of the extracts was determined using atomic absorption.

pH Determination

The soil pH was determined on a Corning pH meter (Model 7) at a 1:2.5 soil water ratio (Jackson, 1959). The pH was also measured using a 1:2.5 soil to 1 N KCl solution ratio.

Potassium Release From Soils

Water-Soluble Potassium

Air dried soil (5 gm) was weighed into a 50 ml centrifuge tube, and distilled water (25 ml) was added. The sample tube was shaken for 10 minutes, centrifuged, and the supernatant decanted into a 100 ml volumetric flask. Two additional extractions were made in the same manner. The combined extract solution was diluted to volume with distilled water. The potassium contents of the water extract were determined using a Perkin-Elmer 107 atomic absorption spectrophotometer.

The water-soluble potassium of silt and clay fractions was not determined, since the particle size separation treatment would have removed water-soluble potassium.

Exchangeable Potassium

Air dried soil (5 gm) was weighed into a 50 ml centrifuge tube, and 1N ammonium acetate pH 7 (25 ml) (Pratt, 1965) was added. The same extracting procedure, as in the water soluble potassium, was followed and the exchangeable potassium was obtained by subtraction of the water soluble potassium from the ammonium acetate extractable potassium. The exchangeable potassium for the sand,

silt, and clay fractions was measured similarly on 5 gm sand, 1 gm silt and 1 gm clay samples.

Boiling HNO₃ Extractable Potassium

A ground air dried soil sample (2.5 gm) was weighed in 125 ml Erlenmeyer flask, and 1N HNO₃ (25 ml) (Pratt, 1965) was added. The soil suspension was boiled gently for 10 minutes, cooled, and filtered through Whatman No. 42 filter paper into a 100 volumetric flask. The soil was washed with 0.1 N HNO₃ (15 ml) and the extract subsequently diluted to volume with 0.1 N HNO₃. The potassium in the extract was determined using atomic absorption spectrophotometer.

The boiling HNO₃ extractable potassium was determined for the soil and for the sand, silt, and clay fractions separately.

Triplicate measurements of water soluble ammonium acetate, and HNO₃ extractable potassium were made on subsamples of soils, clay, silt, and sand. These measurements are presented in Appendix II.

Particle Size Separation

The air dried soil (100 gm) was placed in a stirrer (Hamilton Beach), stirred for five minutes, quantitatively transferred into a 1 liter cylinder and diluted to volume with distilled water.

The sand fraction (2-0.05 mm) of each soil was separated by allowing the sand to settle according to Stock's equation, and siphoning the silt and clay fractions. The silt and clay was siphoned repeatedly until the supernatant was clear.

The silt fraction (0.05-0.002 mm) was separated from the clay using the same technique except that the silt was allowed to settle and the clay was siphoned. The clay fraction (< 0.002 mm) was assumed to be the fraction left after separation of the sand and silt.

Excessive water was removed from the sand, silt, and clay fractions by continuous centrifugation. These fractions were collected as a paste, air dried, and weighed to accurately determine the soil texture.

Silt and Clay Mineral Identification

Qualitative identification of silt and clay potassium-bearing minerals was made using X-ray diffraction techniques. A portion of the silt and clay fractions for each soil was saturated with either magnesium or potassium chloride solutions. Specimens were prepared for X-ray diffraction analysis by smearing the silt or clay paste on petrographic slides (Theisen and Harward, 1962).

The prepared slides received different solvation, equilibration at controlled humidity, and heat treatments. The humidity was

controlled by equilibration prior to as well as during analysis. The following characterization treatments were used:

- 1) Mg - saturation and 54% relative humidity.
- 2) Mg - saturation and ethylene glycol.
- 3) Mg - saturation and glycerol.
- 4) K - saturation and 105^oC and dry air.
- 5) K - saturation and 54% relative humidity.
- 6) K - saturation and 300^oC and dry air.
- 7) K - saturation and 550^oC and dry air.

X-ray diffraction patterns for the silt and clay fractions were obtained with a Norelco diffractometer using Cu K_α radiation and a focusing monochromator.

A brief description of the criteria for identification of the minerals present is presented in the Appendix III.

RESULTS AND DISCUSSION

The soils were divided into five groups in the order of increasing clay content, which also placed the soil groups in geographical areas.

The Quincy and Ephrata soil series located along the Columbia River in eastern Oregon averaged 86, 10 and 4% sand, silt and clay, respectively (Table 2). The Quincy soil had been brought under cultivation within 10 years, producing potatoes, wheat and melons, and the Ephrata soil had been under sprinkler irrigation for about 10 years. Neither of these soils has been cropped intensively for many years and potassium removal has been minimal. Some potassium fertilizer has been applied on the Quincy series but none on the Ephrata series.¹ Experiments showed adequate levels of potassium for potato production on these soils.¹

The Deschutes soils series in the Redmond area have 76, 18 and 6% sand, silt and clay respectively, while the Metolius soil series contains 57, 30, and 13% sand, silt and clay, respectively (Table 2). These soils are relatively shallow, 18 to 24 inches deep, and have produced irrigated alfalfa, grass-legume hay or pasture, and potatoes for 30 to 50 years. The relatively high potassium

¹Information obtained by personal communication and from experiment station reports.

Table 2. Particle size distribution and soil texture classes of the soils studied.

Group #	Soil Series	Sand 2 - 0.005 mm %	Silt 0.05 - 0.002 mm %	Clay < 0.002 mm %	Soil texture class
1	Quincy	87	10	3	Sand
-	Ephrata	85	11	4	Loamy sand
X		86	10.5	3.5	
2	Deschutes	77	18	5	Loamy sand
-	Deschutes	75	19	6	Sandy loam
X		76	18.5	5.5	
3	Poe	73	20	7	Sandy loam
-	Poe	71	21	8	Sandy loam
-	Poe	68	22	10	Sandy loam
X		70.7	21	8.3	
	Henley	61	27	12	Sandy loam
4	Metolius	57	30	13	Sandy loam
-	Madras	51	35	14	Loam
-	Agency	45	40	15	Loam
-	Madras	45	39	16	Loam
-	Madras	40	43	17	Loam
X		48	37	15	
5	Nyssa	22	60	18	Silt loam
-	Nyssa	20	61	19	Silt loam
X		21	60.5	18.5	

requirements for these crops and the shallow rooting zone has resulted in crop removal of readily available potassium. A potassium deficiency has been widespread on potatoes on these soils with rates of 200 to 400 pounds K_2O per acre being recommended when potassium soil test values are low.

The Poe and Henley soils series in the Klamath basin averaged 68, 23 and 9% sand, silt and clay, respectively (Table 2). These soils have a relatively deep profile, 30 to 50 inches. Irrigated alfalfa, potatoes, and cereal crops have been grown on the Poe soils for 40 to 50 years. Potassium removed by crops grown on the Poe soils would not be excessive since spring barley has been a major crop in this area. The Henley soil was selected for its high exchangeable potassium level. It has been placed under sprinkler irrigation within the last five years with minimal potassium removal by crops. Potatoes grown on the Poe and Henley soils do not respond to potassium application.

The Madras soils in Central Oregon have 48, 37, and 15% sand, silt and clay, respectively (Table 2). Soil depth varies from 20 to 30 inches and it is generally greater than the Deschutes series, clay content is higher, and response from potassium on potatoes has not been common. Less potassium, 0 to 60 lbs/A, is applied to the Madras soils as compared to the Deschutes. Irrigated alfalfa, potatoes, clover, grass seed and cereal crops have been produced

for 20 to 30 years on these soils.

The Nyssa soils on the Malheur Experiment Station have 21, 60 and 19% sand, silt, and clay, respectively (Table 2). The Nyssa soils range from 24 to 36 inches in depth. Even though the Nyssa soil has been irrigated for 40 years or more, potassium removal has been relatively low since small grains, corn for grain, and some alfalfa hay have been the main crops produced. No plant response to potassium fertilizers has been observed.

Mineral Analysis

Knowledge of the dominant minerals present in a soil should permit a reasonable prediction of the potassium status in that soil. X-ray diffraction analysis of the clay and silt fractions of the fifteen soils indicated a mixture of potassium-bearing minerals present in all the soils.

Minerals in Clay Fraction

The clay fractions of the soils in groups 1, 4, and 5 contained predominantly smectites and micas (Figures 1, 2 and 3). Smectites were identified by existence of a broad peak at 15 \AA° which expanded to 16.5 \AA° upon solvation with glycerol. Mica was indicated by the presence of a peak at 10 \AA° regardless of the treatment. Relative to smectites and micas, a small peak at 7.1 \AA° was indicative of

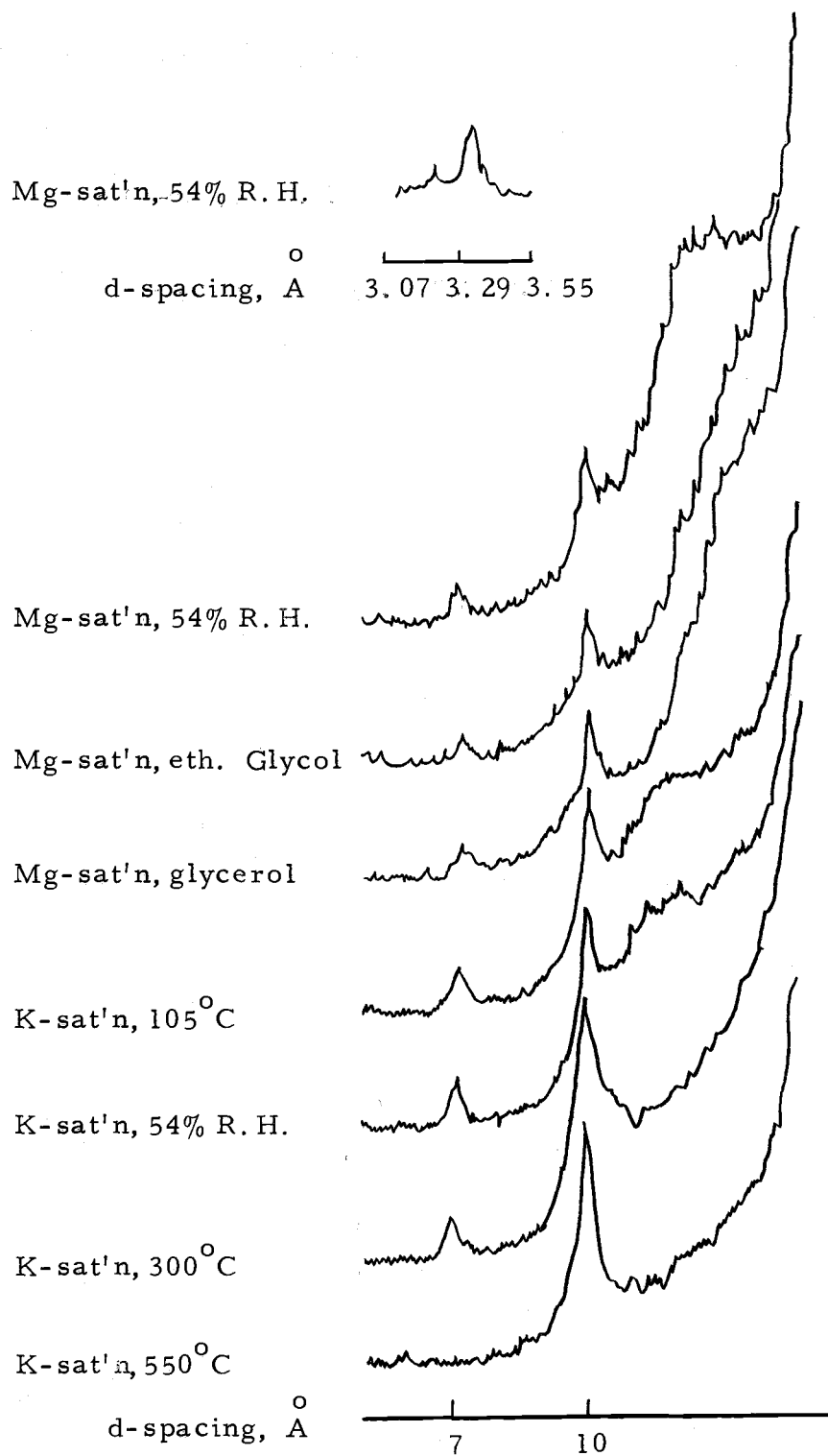


Figure 1. X-ray diffraction patterns of the clay fraction of Ephrata soil (No. 2).

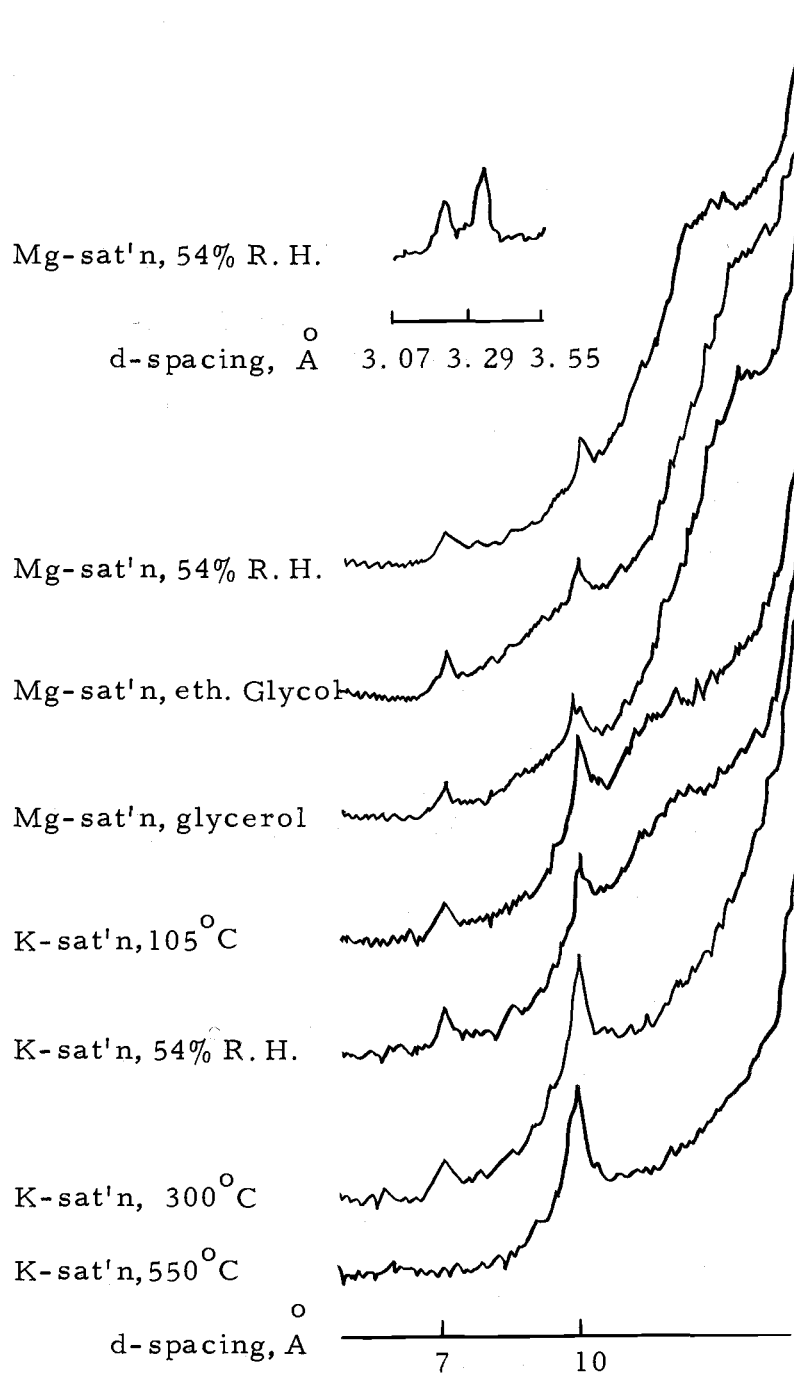


Figure 2. X-ray diffraction patterns of the clay fraction of Madras soil (No. 10).

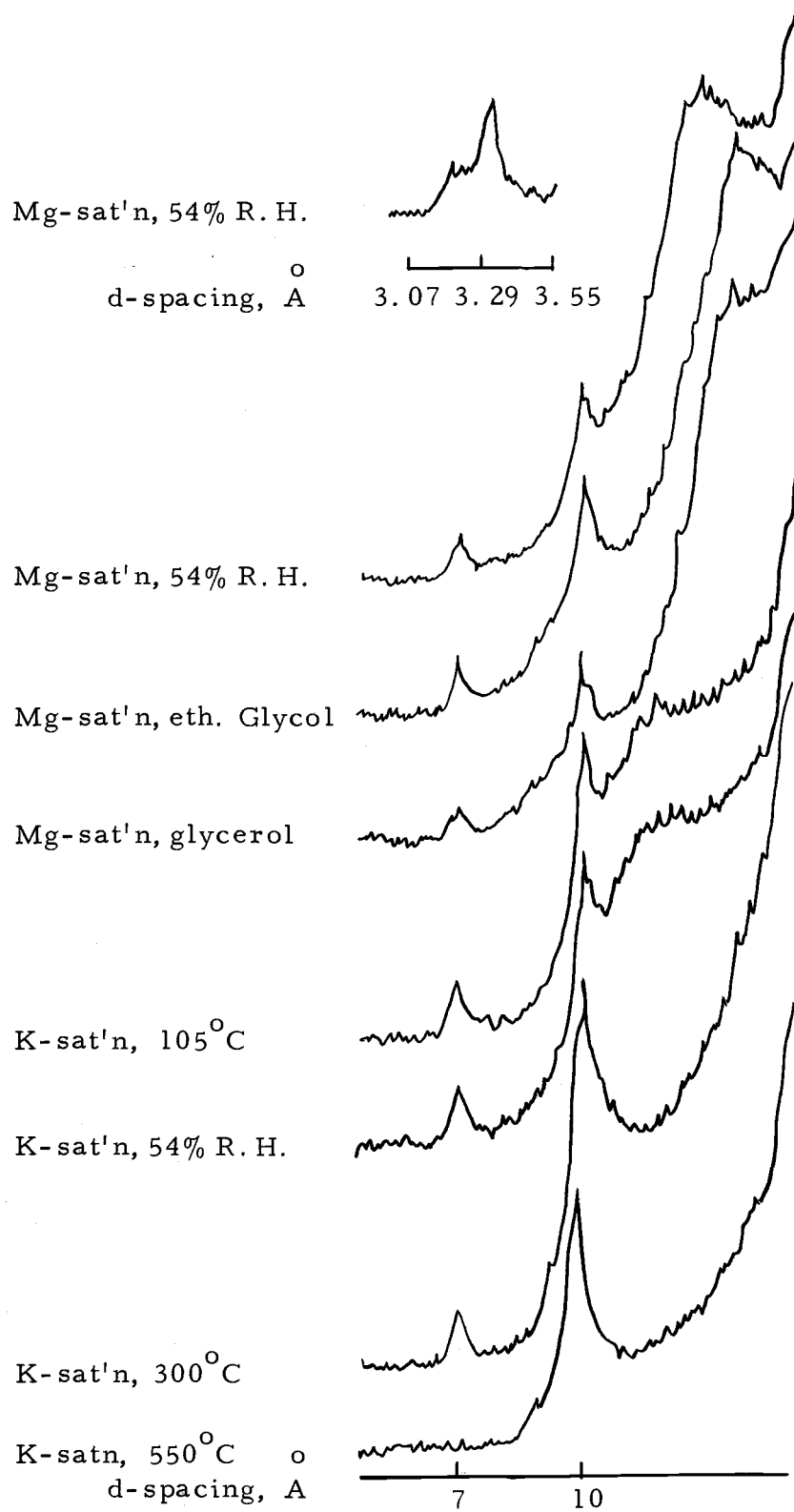


Figure 3. X-ray diffraction patterns of the clay fraction of Nyssa soil (No. 14).

Kaolins in these soils. Traces or small amounts of potassium feldspars were indicated by the presence of small peaks at 3.2 \AA° (Figures 1, 2 and 3). Some vermiculite may be present because the Mg-saturated sample did not expand to a spacing above 14.5 \AA° . Residual vermiculite may occur in a hydroxy interlayer matrix (Brown, 1961).

In contrast to the soils in groups 1, 4 and 5, the clay fraction of the Deschutes, Poe and Henley soils contained large amounts of amorphous materials (Figures 4 and 5). Potassium feldspars were present as evidenced by the peaks at 3.2 \AA° . Mica was present in the Deschutes soils as indicated by the peaks at 10 \AA° (Figure 4). A shoulder between the 14 and 17 \AA° lines collapsed to the 10 \AA° line upon K-saturation treatments, indicating presence of smectites in the Poe soils, was also observed (Figure 5).

Minerals in Silt Fraction

The silt fractions of the Quincy and Ephrata soils contain similar minerals; namely, mica, vermiculite, smectites and Kaolins with potassium feldspars present in larger amounts in the Ephrata than in the Quincy soil (Table 3). The silt fraction of the Deschutes, Poe and Henley soils contained large amounts of amorphous materials (Figures 6 and 7). Smectites and potassium feldspar were the only minerals identified in the Poe and Henley soils

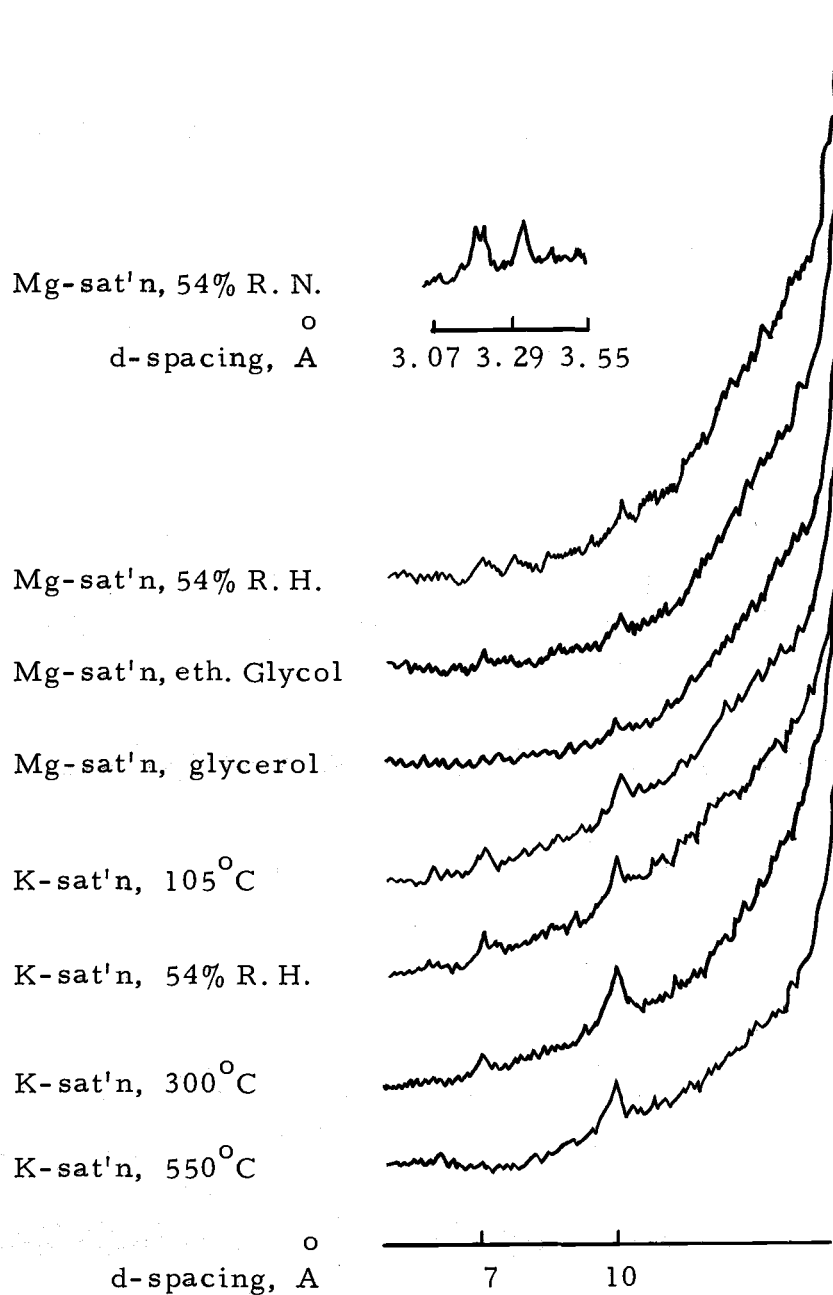


Figure 4. X-ray diffraction patterns of the clay fraction of Deschutes soil (No. 4).

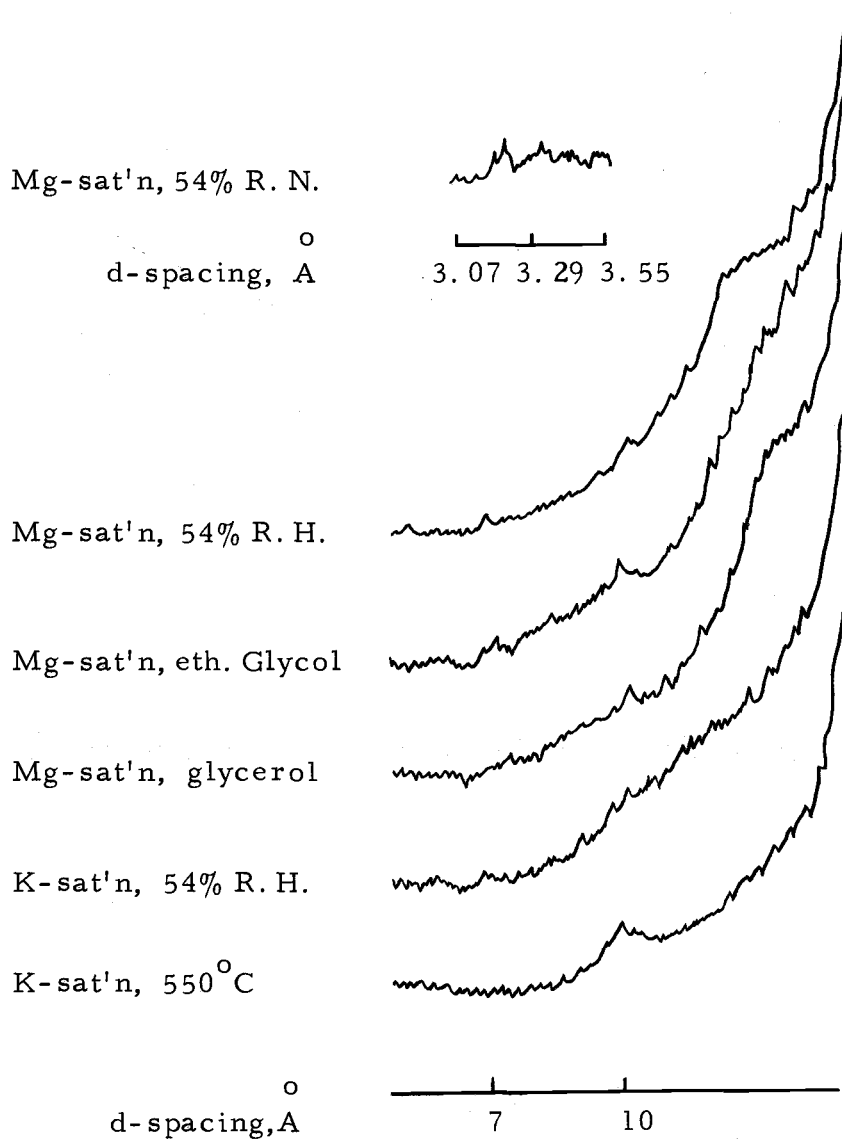


Figure 5. X-ray diffraction patterns of the clay fraction of Poe soil (No. 7).

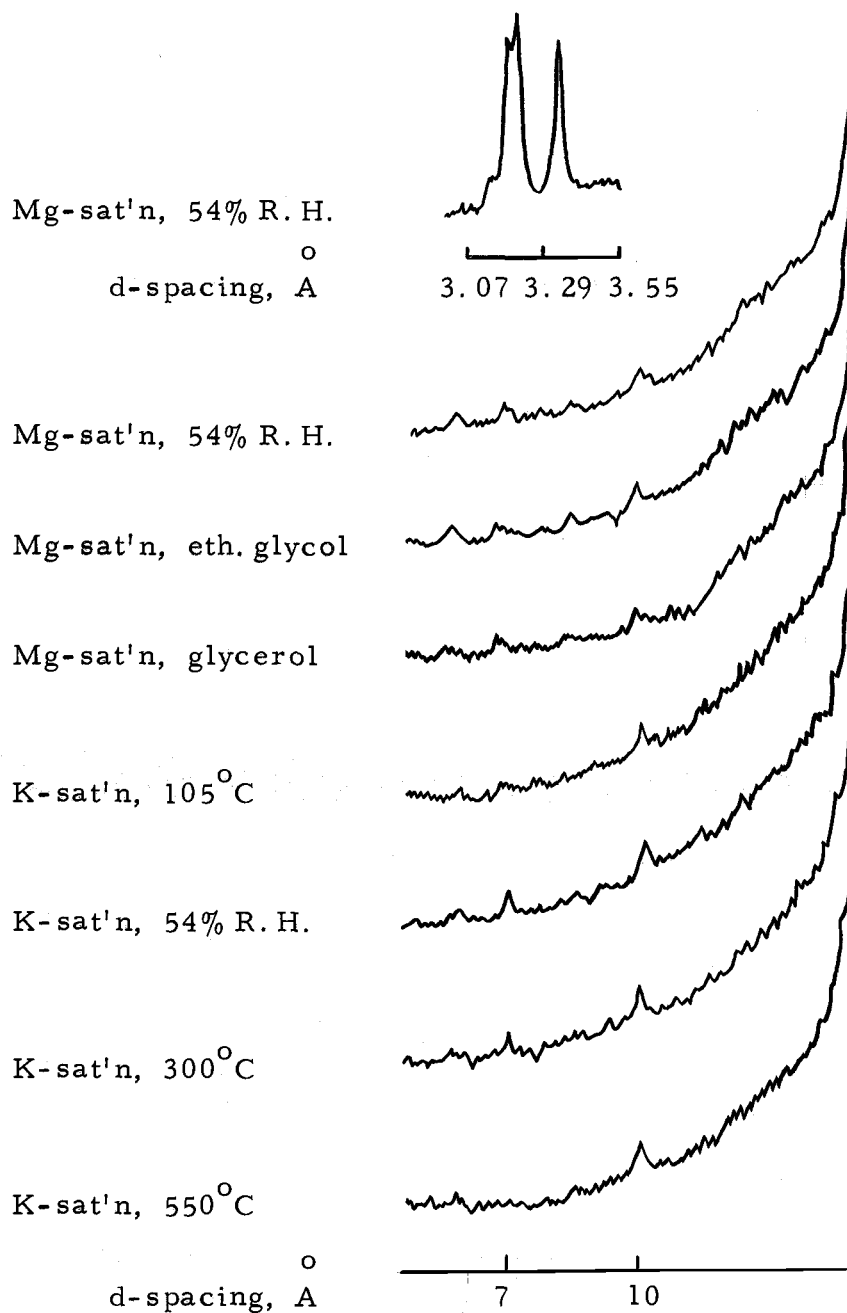


Figure 6. X-ray diffraction patterns of the silt fraction of Deschutes soil (No. 4).

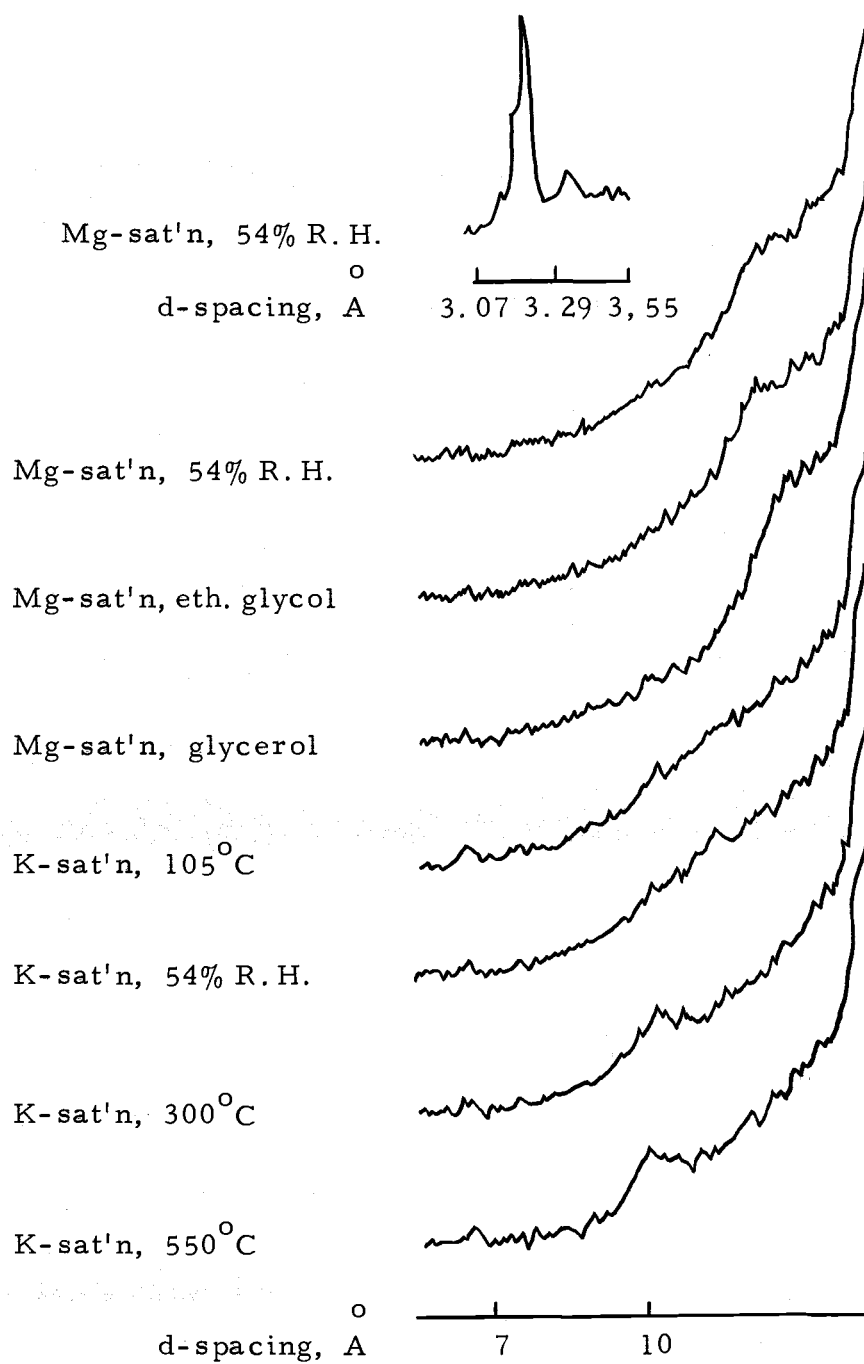


Figure 7. X-ray diffraction patterns of the silt fraction of Poe soil (No. 7).

(Figure 7). The silt fraction of the Deschutes soils contained some micas and kaolins as indicated by small peaks at 10 and $7.1 \overset{\circ}{\text{Å}}$, respectively (Figure 6).

The silt fraction of the soils in groups 1, 4 and 5 contained vermiculite as evidenced by the failure of the Mg-saturated samples to expand beyond the $15 \overset{\circ}{\text{Å}}$ spacing (Figures 8, 9 and 10). Some smectite was probably present in the silt fraction of soils in groups 1, 4 and 5 since some expansion with glycerol treatment occurred (Figures 8, 9 and 10). The $10 \overset{\circ}{\text{Å}}$ mica peak was observed in the X-ray diffraction patterns for the silt fraction of all the soils except for the Poe and Henley soils (Figures 6, 8, 9, and 10). Kaolins were present in small amounts relative to micas, vermiculite and potassium feldspars in the silt fraction of all the soils (Table 3).

In general, potassium feldspars, micas and vermiculite were present in relatively larger amounts and smectites in smaller amounts in silt than in clay fractions of all soils (Table 7). This agrees with the previous investigations reported by Cook and Hutcheson (1960), Somasini and Huang (1971), Jackson (1964), and Fawzi and Drew (1969).

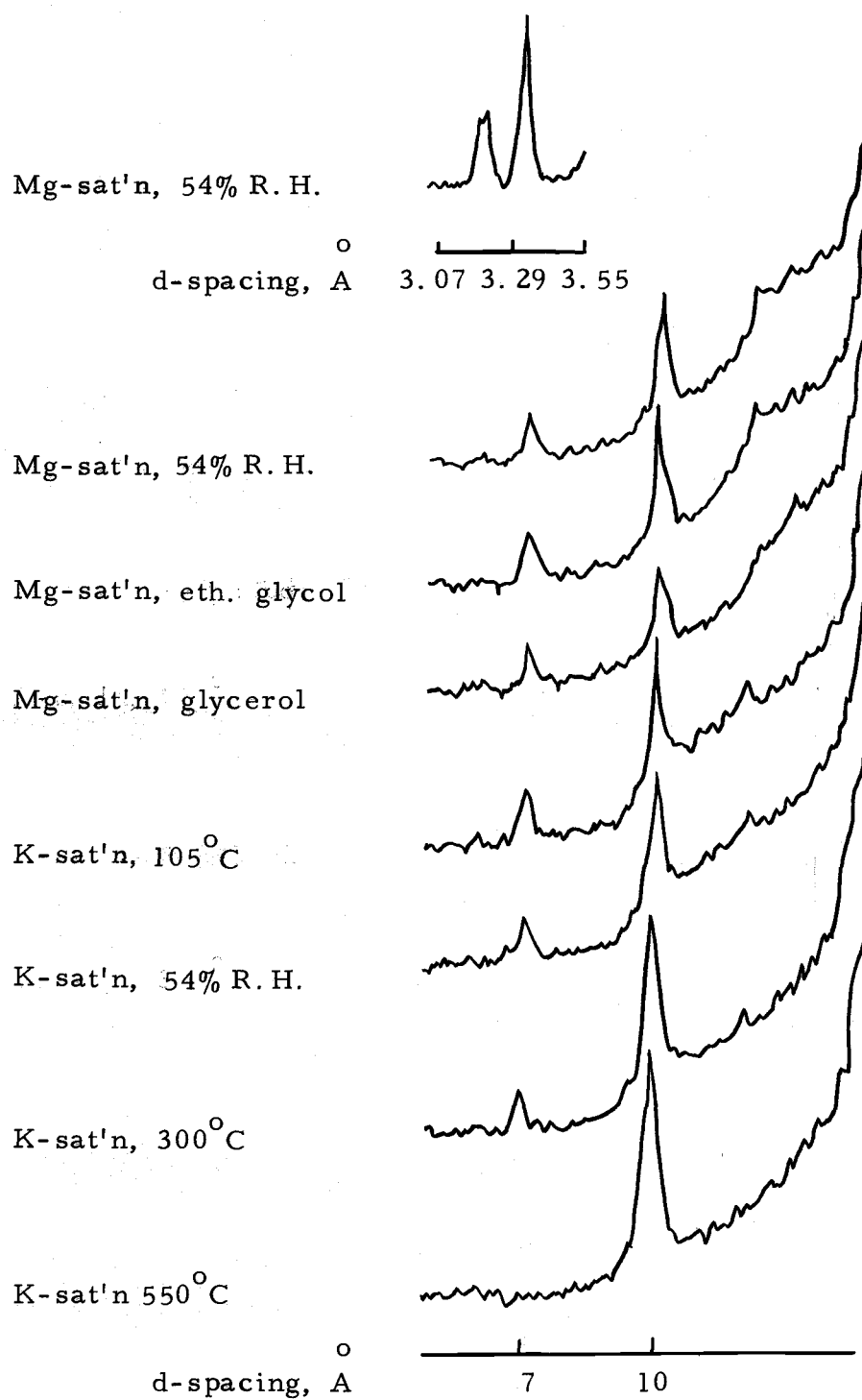


Figure 8. X-ray diffraction patterns of the silt fraction of Ephrata soil (No. 2).

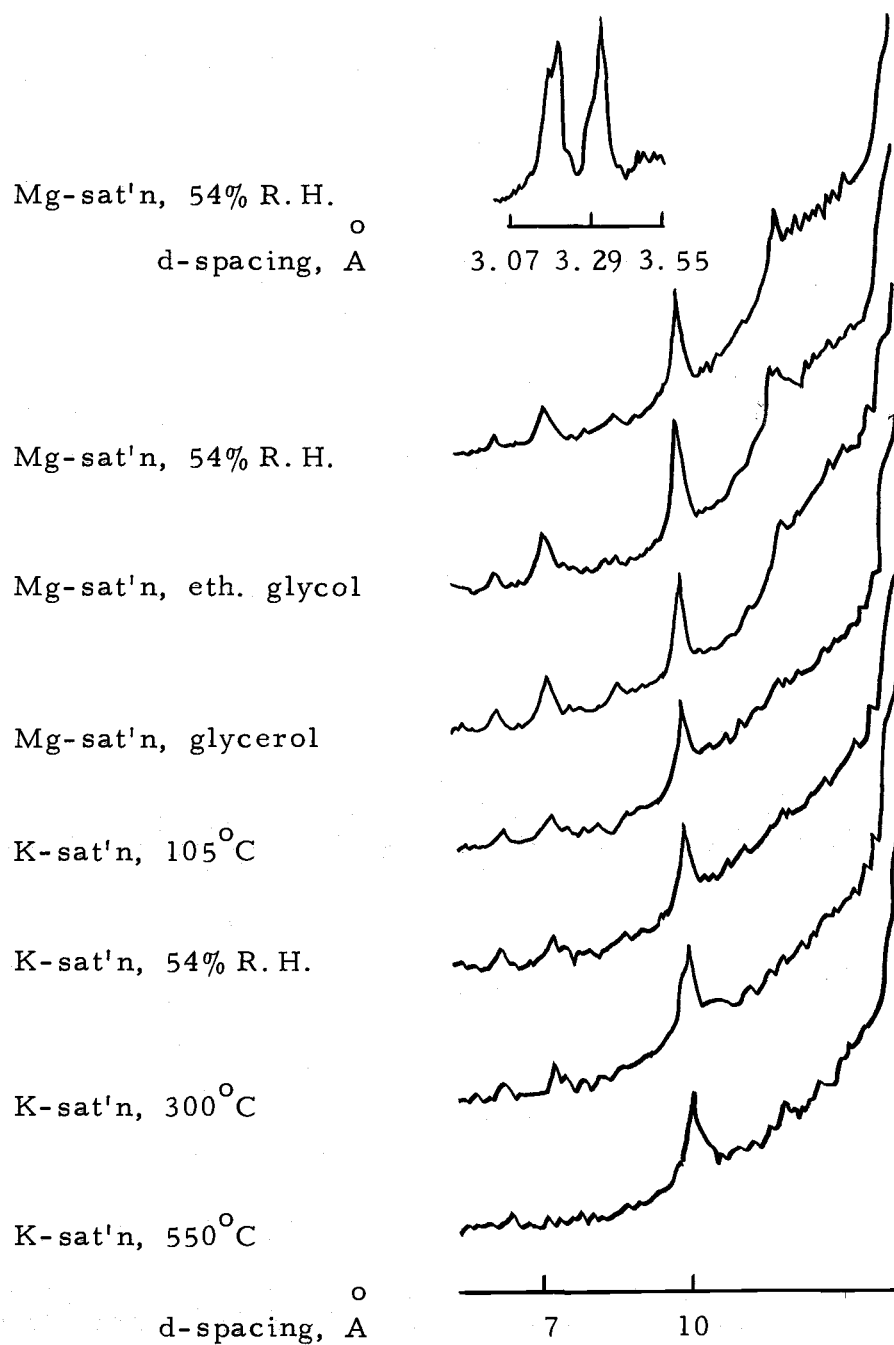


Figure 9. X-ray diffraction patterns of the silt fraction of Madras soil (No. 10).

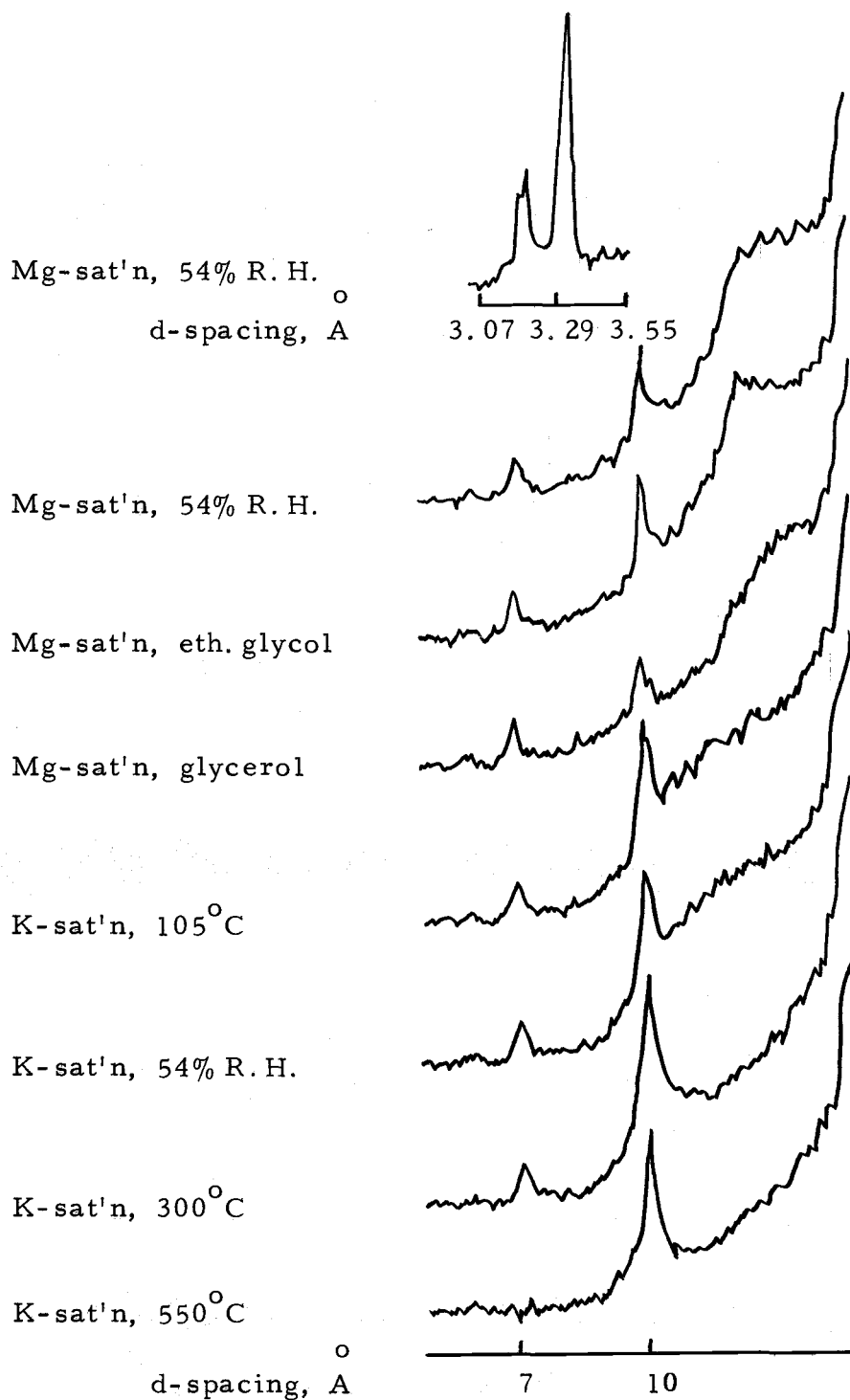


Figure 10. X-ray diffraction patterns of the silt fraction of Nyssa soil (No. 14).

Table 3. Minerals present in clay and silt fractions of soils studied.

Group	Soil	Soil Series	Size Fraction ^a											
			Clay < 0.002 mm						Silt 0.02 - 0.002 mm					
			K	S	V	M	F	A.M.	K	S	V	M	F	A.M.
1	1	Quincy	x	xxx	?	xx	T		x	xx	xx	xxx	xx	
	2	Ephrata	x	xxx	?	xx	T		x	xx	xx	xxx	xxx	
2	3	Deschutes	?	?	?	x	x	xxx	x	?	?	x	xxx	xxx
	4	Deschutes	?	?	?	x	x	xxx	x	?	?	x	xxx	xxx
3	5	Poe	-	x	-	?	x	xxx	-	?	-	-	xxx	xxx
	6	Poe	-	x	-	?	x	xxx	-	?	-	-	xxx	xxx
	7	Poe	-	x	-	?	x	xxx	-	?	?	?	xxx	xxx
	8	Henley	-	x	-	?	x	xxx	-	?	-	-	xxx	xxx
4	9	Metolius	?	xxx	?	x	x		?	x	xxx	xx	xx	
	10	Madras	x	xxx	?	xx	x		x	x	xxx	xx	xx	
	11	Agency	x	xxx	x	xx	x		x	x	xx	xxx	xxx	
	12	Madras	x	xxx	x	xx	x		x	x	xx	xxx	xxx	
	13	Madras	x	xxx	xx	x	x		x	x	xxx	xx	xxx	
	14	Nyssa	x	xxx	?	xx	T		x	xx	xxx	xx	xx	
	15	Nyssa	x	xxx	?	xx	T		x	xx	xx	xxx	xx	

^aSymbols: K = Kaolins; S = Smectites; V = vermiculite; M = micas; F = potassium feldspar;
 x = xsmall amount; xx = moderate amounts; xxx = large amounts; ? = possibly present; T = trace; - = not detected.
 A.M. = amorphous material.

Potassium Release From Soils

Water Soluble Potassium

Water soluble potassium varied greatly and ranged from 8 $\mu\text{g/g}$ in the Deschutes soil series to 90 $\mu\text{g/g}$ in the Poe soil (Table 4). Within each group of soils, the water soluble potassium increased with the clay and silt content. For example, the water soluble potassium increased from 35 $\mu\text{g/gm}$ in the Metolius soil with 30% silt and 13% clay to 86 $\mu\text{g/gm}$ in the Madras soil with 37% and 15% silt and clay, respectively. The water soluble potassium in the Deschutes soils series was only 13 $\mu\text{g/g}$ while in the Poe soils series, the water soluble potassium averaged 61 $\mu\text{g/gm}$. The Deschutes and Poe soils have 76 and 70.7% sand, respectively and contain large amounts of amorphous materials. The Quincy and Ephrata soils series with 86% sand contain about the same water soluble potassium level as the Nyssa soils with 21% sand and similar minerals.

Ammonium Acetate Extractable Potassium

The ammonium acetate extractable potassium levels ranged from 138 $\mu\text{g/gm}$ in the Deschutes soil to 1384 $\mu\text{g/gm}$ in the Henley soil (Table 4). The relatively low levels of exchangeable potassium

Table 4. Water soluble, ammonium acetate extractable^a and boiling HNO₃ extractable potassium present in soil samples.

Group #	Soil Series	K extraction			Non-extractable K %
		H ₂ O	NH ₄ OAc (µg/gm)	HNO ₃	
1	Quincy	30	250	1081	77
—	Ephrata	43	353	1366	74
X		36	302	1224	76
2	Deschutes	8	138	556	75
—	Deschutes	18	253	729	65
X		13	196	643	70
3	Poe	37	317	1001	68
—	Poe	57	417	1180	65
—	Poe	90	718	2002	64
X		61	484	1394	66
	Henley	111	1384	3449	59
4	Metolius	35	305	975	69
—	Madras	47	344	1130	70
—	Agency	62	427	1420	70
—	Madras	67	459	1410	67
—	Madras	86	624	1794	65
X		59	432	1346	68
5	Nyssa	31	513	1856	72
—	Nyssa	42	606	2232	73
X		37	560	2044	73

^aAmmonium acetate extractable potassium includes water soluble and exchangeable potassium.

in the Deschutes soils could probably be associated with relatively higher crop removal of potassium and shallower soil depth than in the Henley soil.

The averages for the readily available potassium of the soils in groups 1, 4 and 5 increased with the clay and silt contents in these groups (Tables 2 and 4). For example, the readily available potassium increased from 302 $\mu\text{g}/\text{gm}$ in group 1 with 3.5% clay and 10.5% silt to 560 $\mu\text{g}/\text{gm}$ in group 5 with 18.5% clay and 60.5% silt. The differences in the ammonium acetate extractable potassium, in general, followed the water soluble potassium trend.

Within each group of soils, the increase in ammonium acetate extractable potassium increased with clay content and decreased with sand content (Tables 2 and 4).

Boiling HNO_3 Extractable Potassium

The boiling HNO_3 extractable potassium levels ranged from 642 $\mu\text{g}/\text{gm}$ in the Deschutes soils with 76% sand and 5.5% clay to 2044 $\mu\text{g}/\text{gm}$ in the Nyssa soils with 21% sand and 18.5% clay (Table 4). The HNO_3 extractable potassium did not correlate with the texture of the soils studied (Tables 2 and 4). However, within each group, the HNO_3 extractable potassium increased with the silt and clay contents. For example, the HNO_3 extractable potassium increased from 975 $\mu\text{g}/\text{gm}$ in the Metolius soil with 30% silt and

13% clay to 1794 $\mu\text{g}/\text{gm}$ in the Madras soil with 43% silt and 17% clay.

Seventy-six percent of the HNO_3 extractable potassium came from non-exchangeable sources (probably micas and vermiculite) in the Quincy and Ephrata soils (Table 4), while the non-exchangeable potassium portion of the HNO_3 extractable potassium in the Henley series was reduced to 59%. Previous workers have reported that hydrous mica and micaceous minerals are the most probably sources of non-exchangeable potassium (Dowdy and Hutcheson, 1963; Cook and Hutcheson, 1960).

The water soluble, ammonium acetate extractable and HNO_3 extractable potassium for the Henley soil was higher than for the other soils in this study. This was expected since the Henley soil was specifically selected to demonstrate the presence of luxuriant amounts of potassium for potato production.

The water soluble, ammonium acetate extractable and HNO_3 extractable potassium levels seemed to correlate with potassium removal by crops grown.

Potassium Release From Clay, Silt and Sand Fractions

Exchangeable Potassium From the Clay

Exchangeable potassium associated with the clay fraction

ranged from 60 $\mu\text{g}/\text{gm}$ of soil in the Deschutes series to 608 $\mu\text{g}/\text{gm}$ of soil in the Henley series (Table 5). Definite differences in the amount of exchangeable potassium per gram of clay for the soils were obtained (Table 5).

The Ephrata and Quincy soils averaged 4125 μg of exchangeable potassium per gram of clay, whereas, Madras, Metolius and Agency soils contained an average of 1259 μg / per gram of clay with the clay minerals being similar (Figures 1 and 2). The crop removal of potassium during the periods that these soils have been brought under cultivation, as indicated in the first part of discussion, however, was different.

The exchangeable potassium from the clay fractions, expressed as a percentage of the total exchangeable potassium in a soil, varied from 48% in the third group to 55% in the first group (Table 5). The soils in groups 1 and 3 had the lowest clay content.

Boiling HNO_3 Extractable Potassium From the Clay

The boiling HNO_3 extractable potassium from the clay fractions ranged from 240 $\mu\text{g}/\text{gm}$ in the Deschutes soil to 1468 $\mu\text{g}/\text{gm}$ in the Henley soil (Table 5). The Quincy and Ephrata soils contained the highest level of 13725 μg of HNO_3 extractable potassium per gram of clay, whereas, the Madras, Metolius, and Agency soils averaged 3501 μg of HNO_3 extractable potassium per gram of clay (Table 5).

Table 5. Ammonium acetate and boiling HNO₃ extractable potassium from the clay fraction of the soils.

Group #	Soil Series	NH ₄ OAc extractable K			Boiling HNO ₃ extractable K			Non-exchangeable K %
		µg/gm ^a of soil	% of total in clay	µg/gm of clay	µg/gm ^a of soil	% of total in clay	µg/gm of clay	
1	Quincy	120	55	4000	432	41	14400	72
-	Ephrata	170	55	4250	522	39	13050	68
X		145	55	4125	477	40	13725	70
2	Deschutes	60	46	1200	240	44	4800	75
-	Deschutes	134	58	2255	342	48	5700	61
X		97	52	1727	291	46	5250	68
3	Poe	140	50	2000	400	41	5714	65
-	Poe	170	47	2125	496	44	6200	65
-	Poe	291	46	2910	832	43	8310	65
X		200	48	2345	576	43	6741	65
	Henley	608	48	5067	1468	44	12233	60
4	Metolius	145	54	1115	435	46	3346	66
	Madras	150	51	1071	460	43	3286	67
	Agency	203	56	1353	543	40	3620	63
	Madras	215	55	1344	549	42	3431	61
-	Madras	240	45	1412	650	39	3824	63
X		191	52	1259	527	42	3501	64
5	Nyssa	235	49	1306	700	38	3889	66
-	Nyssa	293	52	1542	975	44	5132	70
X		264	51	1424	838	41	4511	68

^aThe amount of potassium contributed by the clay fraction in the soil.

This again suggests the importance of the period that these soils have been brought under cultivation since they contain similar clay minerals (Figures 1 and 2).

The HNO_3 extractable potassium from the clay increased with the clay content if the soils were placed in two groups, high and low amounts of amorphous materials (Tables 3 and 4). For example, the HNO_3 extractable potassium increased from 477 $\mu\text{g}/\text{gm}$ in the Quincy and Ephrata soils to 838 $\mu\text{g}/\text{gm}$ in the Nyssa soils with low amorphous materials and increased from 291 $\mu\text{g}/\text{gm}$ in the Deschutes soils to 799 $\mu\text{g}/\text{gm}$ in the Poe and Henley soils which contained larger amounts of amorphous materials. In general, the HNO_3 extractable potassium from the clays of all the soils contributed 40 to 46% of the total HNO_3 extractable potassium from these soils (Table 5).

Exchangeable Potassium From the Silt

The exchangeable potassium associated with the silt varied from 55 $\mu\text{g}/\text{gm}$ in the Deschutes soil to 470 $\mu\text{g}/\text{gm}$ in the Henley soil (Table 6). The soils in groups 1 and 3 averaged 757 and 962 μg of exchangeable potassium per gram of silt, respectively (Table 6). The Madras, Metolius and Agency soils averaged only 312 μg of exchangeable potassium per gram of silt. The Quincy and Ephrata soils probably contained more smectites but similar amounts

Table 6. Ammonium acetate and boiling HNO₃ extractable potassium from the silt fraction of the soils.

Group #	Soil Series	Ammonium acetate extractable K			Boiling HNO ₃ extractable K			Non-exchangeable K %
		µg/gm ^a of soil	% of total in silt	µg/gm of silt	µg/gm ^a of soil	% of total in silt	µg/gm in silt	
1	Quincy	65	29	650	535	51	5350	88
—	Ephrata	95	31	864	671	51	6100	86
X		80	30	757	603	51	5725	87
2	Deschutes	55	42	306	260	47	1444	79
—	Deschutes	73	32	384	294	41	1547	75
X		64	37	345	277	44	1496	77
3	Poe	100	36	500	436	45	2175	77
	Poe	130	36	624	520	46	2471	75
—	Poe	216	35	982	836	44	3800	74
X		149	36	702	597	45	2815	75
	Henley	470	37	1740	1484	45	5496	68
4	Metolius	84	31	280	399	43	1330	79
	Madras	90	30	257	486	45	1389	81
	Agency	96	26	240	564	42	1410	83
	Madras	112	29	287	562	42	1441	80
—	Madras	214	40	298	844	49	1963	75
X		119	31	312	571	44	1501	80
5	Nyssa	211	44	352	927	51	1543	77
—	Nyssa	245	43	402	1055	48	1730	77
X		228	44	377	991	49	1637	77

^aThe amount of potassium contributed by the silt fraction in the soil.

of micas and vermiculite as the Madras, Metolius and Agency soils (Figures 8 and 9). The differences in the exchangeable potassium associated with the silt fraction of soils in groups 1 and 4 suggest the significance of smectites in the potassium exchange reactions.

When the soils were arranged in groups containing low and high quantities of amorphous material, the exchangeable potassium increased with the silt content (Tables 2 and 6). For example, the exchangeable potassium associated with the silt fraction increased from 84 $\mu\text{g}/\text{gm}$ in the Metolius soil with 30% silt content to 214 $\mu\text{g}/\text{gm}$ in the Madras soil with 43% silt content. Both soils contained no or small amounts of amorphous materials. On the other hand, the exchangeable potassium associated with silt fraction increased from 55 $\mu\text{g}/\text{gm}$ in the Deschutes soil with 18% silt to 470 $\mu\text{g}/\text{gm}$ in the Henley soil with 27% silt. Both soils contained large quantities of amorphous materials.

Boiling HNO_3 Extractable Potassium From the Silt

The average amounts of HNO_3 extractable potassium contributed by the silt were 3 to 6 times more than that extracted by the ammonium acetate and ranged from 250 $\mu\text{g}/\text{gm}$ in the Deschutes soil series to 1484 $\mu\text{g}/\text{gm}$ in the Henley soil series (Table 6). The Quincy, Ephrata and Henley soils contained extremely high HNO_3 extractable potassium per gram of silt (Table 6), which suggests the

presence of micas and vermiculite (Figure 8). However, mica and vermiculite were not observed in the Henley soil due to the presence of large amounts of amorphous materials (Figure 7).

The HNO_3 extractable potassium from the silt of the Metolius, Madras, Agency and Nyssa soils increased from 399 $\mu\text{g}/\text{gm}$ to 1055 $\mu\text{g}/\text{gm}$ with the increase in the silt content. Non-exchangeable potassium made up most of the HNO_3 extractable potassium with the percentage ranging from 74% in the Poe and Henley soils to 87% in the Quincy and Ephrata soils (Table 6).

The potassium extracted by either HNO_3 or ammonium acetate per gram of silt in all the soils was lower than that extracted per gram of clay (Tables 5 and 6). This agrees with the data reported by Maclean and Brydon (1963) and Smith *et al.* (1968).

Exchangeable Potassium From the Sand

The highest value for the exchangeable potassium was 180 $\mu\text{g}/\text{gm}$ contributed by the sand fraction of the Henley soil which represents 14% of the total exchangeable potassium (Table 7). The lowest value for the exchangeable potassium was 15 μg in the Deschutes soil which represented 11% of the total exchangeable potassium in this soil.

The exchangeable potassium increased with the decrease in the sand content within each group of soils except for group #5

Table 7. Ammonium acetate and boiling HNO₃ extractable potassium from the sand fraction of the soils.

Group #	Soil Series	Ammonium acetate extractable K			Boiling HNO ₃ extractable K			
		µg/gm ^a of soil	% of total in sand	µg/gm of sand	µg/gm ^a of soil	% of total in sand	µg/gm of sand	Non-exchangeable K %
1	Quincy	34	15	39	81	8	92	58
—	Ephrata	40	13	47	125	10	147	68
X		37	14	43	103	9	120	63
2	Deschutes	15	11	19	40	8	52	62
—	Deschutes	25	11	33	70	10	93	64
X		20	11	26	55	9	73	63
3	Poe	41	14	55	105	9	178	45
—	Poe	55	15	77	130	13	148	69
—	Poe	120	19	176	236	12	347	49
X		72	16	103	157	11	224	54
	Henley	180	14	295	380	30	623	53
4	Metolius	40	15	70	100	11	175	60
	Madras	52	18	104	135	12	262	60
	Agency	60	16	133	245	18	544	75
	Madras	60	15	133	225	17	500	73
—	Madras	80	15	200	210	12	525	62
X		73	16	128	183	14	401	66
5	Nyssa	38	8	173	190	10	864	80
—	Nyssa	26	4	125	158	8	790	84
X		32	6	149	174	9	827	82

^aThe amount of potassium contributed by the sand fraction in the soil.

(Tables 2 and 7). This is logical since the sands are known to have low exchange capacity due to the nature of their mineralogical structure and composition, being mostly quartz and feldspars (Jackson, 1964). Quartz consists of a continuous framework of silica tetrahedra. All four oxygens of the tetrahedra are shared and there are no cleavage planes. The feldspar structure consists of tetrahedra which are linked together by sharing each oxygen atom between adjacent tetrahedra. The tetrahedra contain mainly Si ions with considerable Al substitution. For each Al ion substituted, one equivalent of a larger cation, such as potassium ion, is present to maintain electrical neutrality.

Boiling HNO₃ Extractable Potassium From the Sand

The values for the boiling HNO₃ extractable potassium from the sand fraction varied and followed the general trend for the exchangeable potassium (Table 7).

SUMMARY AND CONCLUSIONS

The objective of this study was to investigate the potassium status of selected soils from central and eastern Oregon. The minerals present in clay and silt, and the potassium extracted with water, ammonium acetate and HNO_3 from the soil and from each size fraction was evaluated on soils where response from potassium fertilization for potato production had been evaluated.

The exchangeable potassium contributed by each size fraction decreased with the increase in particle size (Table 8). The exchangeable potassium associated with the clay ranged from 48% of the total exchangeable potassium in the Poe and Henley soils series to 55% in the Quincy and Ephrata soils. On the other hand, the exchangeable potassium contributed by the sand fraction varied from 6% of the total exchangeable potassium in the Nyssa soils to 18% in the Poe and Madras soils (Table 8).

The summation of the exchangeable potassium contributed by the different size fractions in each soil, agreed well with the exchangeable potassium level measured in the whole soil (Table 8). For example, the summations of the exchangeable potassium contributed by the clay, silt and sand fractions of the Quincy and Ephrata, Deschutes and Nyssa soils were 1219, 636 and 2040 $\mu\text{g}/\text{gm}$, respectively, where the exchangeable potassium obtained from

Table 8. Ammonium acetate extractable potassium contributed by the clay, silt, and sand compared to that extracted from the whole soil.

Group #	Soil Series	Clay		Silt		Sand		Water soluble K	Σ	NH ₄ OAc extractable K
		μg/gm of soil	% of Total	μg/gm of soil	% of Total	μg/gm of soil	% of Total	μg/gm of soil		μg/gm of soil
1	Quincy	120	55	65	29	34	15	30	249	250
	Ephrata	170	55	95	31	40	13	43	348	353
	X	145	55	80	30	37	14	36	298	302
2	Deschutes	60	46	55	42	15	11	8	138	138
	Deschutes	134	58	73	32	25	11	18	250	253
	X	97	52	64	37	20	11	13	194	196
3	Poe	140	50	100	36	41	14	37	318	317
	Poe	170	47	130	36	55	15	57	412	417
	Poe	291	46	216	35	120	18	90	717	718
	X	200	48	149	36	72	16	61	482	484
	Henley	608	48	470	37	180	14	111	1369	1384
4	Metolius	145	54	84	31	40	15	35	304	305
	Madras	150	51	90	30	52	18	47	339	344
	Agency	203	56	96	26	60	16	62	421	427
	Madras	215	55	112	29	60	15	67	454	459
	Madras	240	45	214	40	80	16	86	620	624
X	191	52	119	31	73	16	59	442	432	
5	Nyssa	235	49	211	44	38	8	31	515	513
	Nyssa	293	52	245	43	26	4	42	606	606
	X	264	51	228	44	32	6	37	561	560

these soils was 1224, 643, and 2044 $\mu\text{g}/\text{gm}$, respectively.

The HNO_3 extractable potassium contributed by the silt fraction exceeded that contributed by the clay or the sand fractions in all the soils, except for the Deschutes and Metolius soils (Table 9). The sand fractions of Quincy, Ephrata, Deschutes and Nyssa soils contributed 9% of the total HNO_3 extractable potassium extracted from these soils (Table 9). The summation of the HNO_3 extractable potassium from the clay, silt and sand fraction in each soil agreed closely with the values obtained from the whole soil (Table 9).

The clay and silt fractions of the Deschutes, Poe and Henley soils series were dominated by amorphous materials with minimum indication of other minerals being present. These soils represented the extremes in ammonium acetate and HNO_3 extractable potassium with the Deschutes soils having 196 μg and 643 μg of ammonium acetate and HNO_3 extractable potassium per gram of soil, respectively, while the Henley soil contained 1384 μg and 3449 μg of ammonium acetate and HNO_3 extractable potassium per gram of soil, respectively. The Deschutes soils were selected to represent soils with maximum potassium response while the Poe #7 and Henley soils were selected for their high potassium levels.

In contrast, groups 1, 4 and 5--the Quincy, Ephrata, Metolius, Madras, Agency and Nyssa soils series--contained no amorphous material, with smectites and micas being the dominant minerals

Table 9. Boiling HNO₃ extractable potassium contributed by the clay, silt, and sand compared to that extracted from the whole soil.

Group #	Soil Series	Clay		Silt		Sand		Water soluble K	Σ	HNO ₃ extractable K
		μg/gm of soil	% of Total	μg/gm of soil	% of Total	μg/gm of soil	% of Total	μg/gm of soil		μg/gm of soil
1	Quincy	432	41	535	51	80	8	30	1077	1081
—	Ephrata	522	39	671	51	125	10	43	1361	1366
X		477	40	603	51	103	9	36	1219	1224
2	Deschutes	240	44	260	47	40	8	8	548	556
—	Deschutes	342	48	294	41	70	10	18	724	729
X		291	46	277	44	55	9	13	636	643
3	Poe	400	41	436	45	105	9	37	978	1001
	Poe	496	44	520	46	130	13	57	1203	1180
—	Poe	832	43	836	44	236	12	90	1994	2002
X		576	43	597	45	157	11	61	1391	1394
	Henley	1468	44	1484	45	380	11	111	3443	3449
4	Metolius	435	46	399	43	100	11	35	969	975
	Madras	460	43	486	45	135	12	47	1128	1130
	Agency	543	40	564	42	245	18	62	1414	1420
	Madras	549	42	562	42	225	17	67	1403	1410
—	Madras	650	39	844	49	210	12	86	1790	1794
X		527	42	571	44	183	14	59	1340	1346
5	Nyssa	700	38	927	51	190	10	31	1848	1856
—	Nyssa	975	44	1055	48	158	8	42	2230	2232
X		838	41	991	49	174	9	37	2040	2044

in the clay fraction; and vermiculite, micas and feldspars being the dominant minerals in the silt fractions. These soils also represented a range in crop response to potassium fertilization. Potassium response was found on the Metolius, Agency and Madras #10 but not on the Nyssa and Madras (#12 and 13) soils.

The soils included in this study also represent a wide range in particle size, especially in the sand and silt fractions. The two groups with the highest sand and lowest clay contents, the Quincy, Ephrata, and Deschutes, provide a contrast in response from potassium with marked potassium response on the Deschutes soils and no response on the Quincy and Ephrata soils. On the other end of the scale, the Madras and Nyssa soils had the lowest sand and the highest clay contents with somewhat similar mineral composition in both silt and clay fractions.

Crop removal of potassium and depth of rooting zone undoubtedly influenced the potassium status of soils. The Deschutes soils have been irrigated for 30 to 50 years with heavy production of potatoes and legume forage crops that have high potassium requirements for crop production. Also, the Deschutes soils have the shallowest soil profile of any of the soils studied and approach the low clay content of the Quincy and Ephrata soils. The above factors are probably the main reasons for the low potassium levels in the Deschutes soils (Table 4). While the Quincy and Ephrata soils

contain the highest sand (86%) and the lowest clay (3.5%) contents, they have been cropped intensively for less than 10 years and the Quincy soil location had received some potassium fertilization.

Critical potassium levels of about 440 $\mu\text{g}/\text{gm}$ for ammonium acetate or 1400 $\mu\text{g}/\text{gm}$ for HNO_3 could be established for all soils from Central Oregon. This would separate the soils in this area on which response from potassium was measured except for the HNO_3 extractable potassium value on Agency soil which is very close to the suggested critical level. However, when these critical levels are used on the soils from other areas, the soils on which response from potassium fertilization might be measured, are not identified.

The Quincy, Ephrata, and Poe #5 and 6 all have ammonium acetate and HNO_3 extractable values below the suggested critical level for Central Oregon soils and did not show a response from potassium fertilization. While the Deschutes soils with the largest responses from potassium could be identified at a critical level of 250 $\mu\text{g}/\text{gm}$ for ammonium acetate or 730 $\mu\text{g}/\text{gm}$ for HNO_3 , the Madras #10 and Metolius soils on which potassium response was measured would be in the same classification. However, the Poe (#5 and 6), Quincy and Ephrata soils did not show a response from potassium fertilization even though they fall under the same category with regard to the potassium extracted from these soils.

The Poe #7, Henley, Madras #12 and 13, and Nyssa soils all

had ammonium acetate extractable potassium values above 44 $\mu\text{g}/\text{gm}$ and HNO_3 extractable values above 1400 $\mu\text{g}/\text{gm}$ and did not show response from potassium fertilization.

In summary, it will be necessary to establish separate critical potassium soil test values for both ammonium acetate and HNO_3 when soils from different areas with marked differences in parent material, minerals present, texture, and potassium crop removal are evaluated for response from potassium fertilization.

In evaluating the several factors that influence the potassium status of the soils studied, the following conclusions are probably justified:

1. The water, ammonium acetate and HNO_3 extractable potassium extracted from any one group of soils, increased with the increase in clay and silt and the decrease in sand. The exchangeable potassium contributed by each size fraction decreased with the increase in particle size. The HNO_3 extractable potassium contributed by the silt fraction exceeded that contributed by the clay or the sand fractions.

2. The exchangeable potassium associated with the clay fraction correlated with smectites. The HNO_3 extractable potassium associated with the silt fraction correlated with mica, vermiculite and potassium feldspar. The higher percentage (76%) of HNO_3 extractable potassium, in the Quincy and Ephrata soils, had come

from non-exchangeable sources, probably mica and vermiculite, whereas in the Henley soil with large amorphous material, this percentage was only 59. However, the low levels of potassium released from the Deschutes soils and the high levels of potassium released from the Henley soil indicate the lack of relationship between the amounts of amorphous materials and the levels of potassium released since both soils contain large quantities of amorphous material. The problems of clay minerals identification are such that several similar minerals were identified over a fairly wide geographical area like eastern Oregon and quantitative comparisons of the amounts of a specific mineral present in two different areas are very difficult.

3. Separate critical potassium soil test values should be established for ammonium acetate and HNO_3 when soils from different areas are evaluated for response from potassium fertilization.

4. The silt and clay contents, soil depth, minerals present, cropping system, soil management practices must be considered to evaluate the response from potassium for a specific crop and a specific soil analysis procedure used to measure available potassium for relatively similar groups of soils. Potassium fertilization recommendations should be based primarily on the relationships between a soil test value and potassium response on field experiments on similar groups of soils for each crop.

BIBLIOGRAPHY

- Abed, Fawzi M. A. H. and James V. Drew. 1966. The importance of illite as a source of potassium in Nebraska soils. *Soil Sci. Soc. Amer. Proceedings.* 30:242-245.
- Acquaye, D. K., A. J. MacLean and H. M. Rice. 1967. Potential and capacity of potassium in some representative soils of Ghana. *Soil Sci.* 103:79-89.
- Arnold, P. W. 1962. Soil potassium and its availability to plants. *Outlook on Agr.* 3:263-267.
- Attoe, O. J. and E. Truog. 1945. Exchangeable and acid soluble potassium as regards availability and reciprocal relationships. *Soil Sci. Soc. Amer. Proceedings.* 10:81-86.
- Barshad, 1954. II. Replaceability of ammonium and potassium from vermiculite, biotite, and montmorillonite. *Soil Sci.* 78:57-76.
- Brown, George. 1961. The X-ray identification and crystal structures of clay minerals. Mineralogical Society, London.
- Cook, M. G. and T. B. Hutcheson. 1960. Soil potassium as related to clay mineralogy of selected Kentucky soils. *Soil Sci. Soc. Amer. Proceedings.* 24:252-256.
- Conyers, E. S. and E. O. McLean. 1969. Plant uptake and chemical extractions for evaluating potassium release characteristics of soils. *Soil Sci. Soc. Amer. Proceedings.* 33:226-230.
- DeMumbrum, L. E. 1959. Exchangeable potassium levels in vermiculite and K-depleted micas, and implications relative to potassium levels in soils. *Soil Sci. Soc. Amer. Proceedings.* 23:192-194.
- Doll, E. C., M. M. Mortland, K. Lawton and B. G. Ellis. 1965. Release of potassium from soil fractions during cropping. *Soil Sci. Soc. Amer. Proceedings.* 29:699-702.

- Dowdy, R. H. and T. B. Hutcheson. 1963. Effect of exchangeable potassium levels and drying on release and fixation of potassium by soils as related to clay mineralogy. *Soil Sci. Soc. Amer. Proceedings*. 27:31-34.
- Ellis, B. G. and M. M. Mortland. 1959. Rate of potassium release from fixed and native forms. *Soil Sci. Soc. Amer. Proceedings* 23:451-453.
- Harward, M. E., D. D. Carstea and A. H. Sayegh. 1969. Clays and Clay Minerals. 16:437-447.
- Harward, M. E. and G. W. Brindly. 1965. Swelling properties of synthetic smectites in relation to lattice substitutions. *Clays and Clay Minerals, Proceedings of 13th National Conf.* :209-222.
- Hipp, Billy W. and G. W. Thomas. 1967. Influence of soil clay type on potassium availability. Texas A & M University. *Texas Agr. Expt. Sta. Bull.* MP-829:1-11.
- Igbo unamba-Oparah. 1972. Exchangeable, reserve potassium, and other cation reserves in the Agodi and Adio soils. *Soil Sci.* 113:394-409.
- Jackson, M. L. 1958. *Soil chemical analysis*. Prentice-Hall, Englewood Cliffs, N. J. p. 151-154.
- Jackson, M. L. 1964. Chemical composition of soils, In: F. E. Bear (ed.) *Chemistry of the Soil* 2nd ed. Reinhold Publishing Corp., New York, p. 71-141.
- Legy, J. O. and J. H. Axley. 1959. Investigation of a thermal method for the determination of fixed potassium in soils. *Soil Sci. Soc. Amer. Proceedings* 22:287-290.
- MacLean, A. J. and J. E. Brydon. 1963. Release and fixation of potassium in different size fractions of some Canadian soils as related to their mineralogy. *Can. J. Soil Sci.* 43:123-134.
- McLean, E. O. and R. H. Simon. Potassium release and fixation in Ohio soils as measured by cropping and chemical extraction. Wooster, 1958 (Ohio Agri. Expt. Station. Research Bulletin 824)

- Mortland, M. M. 1958. Kinetics of potassium release. *Soil Sci. Soc. Amer. Proceedings* 22:503-508.
- Nash, V. E. 1971. Potassium release characteristics of some soils of the Mississippi coastal plain as revealed by various extracting agents. *Soil Sci.* 111:313-317.
- Nelson, L. E. 1959. A comparison of several methods for evaluating the K- status of some Mississippi soils. *Soil Sci. Soc. Amer. Proceedings* 23:313-316.
- Nuttall, W. F., B. P. Warkentin and A. L. Carter. 1967. A' values of potassium related to other indexes of soil potassium availability. *Soil Sci. Soc. Amer. Proceedings* 31:344-348.
- Oliveira, V., A. E. Ludwick and M. T. Beatty. 1971. Potassium removed from some southern Brazilian soils by exhaustive cropping and chemical extraction methods. *Soil Sci. Soc. Amer. Proceedings* 35:763-767.
- Peech, M. and R. Bradfield. 1943. The effect of lime and magnesia on the soil potassium and on the absorption of potassium by plants. *Soil Sci.* 55:37-48.
- Pope, A. and H. B. Cheney. 1957. The potassium supplying power of several western Oregon soils. *Soil Sci. Soc. Amer. Proceedings* 21:75-79.
- Pratt, P. F. 1965. Potassium. In: C. A. Black (ed.) *Methods of soil analysis, part 2.* (Agron. Monogr. 9). Amer. Soc. Agron., Madison, Wisconsin, p. 1022-1030.
- Reitemeier, R. F. 1951. Soil potassium. *Advances in Agronomy* 3:113-164.
- Salmon, R. C. 1964. Potassium in different fractions of some Rhodesian soils. *Rhodesian Jour. Agr. Res.* 2:85-90.
- Sayegh, A. H., M. E. Harward and E. G. Knox. 1965. Humidity and temperature interaction with respect to K- saturated expanding clay minerals. *American Mineralogist* 50:490-495.
- Schollenberger, C. J. and R. H. Simon. 1945. Determination of exchange capacity and exchangeable bases in soils - ammonium acetate method. *Soil Sci.* 59:13-24.

- Scott, A. D. 1968. Effect of particle size on interlayer potassium exchange in micas. *Int. Congr. Soil Sci., Trans. 9th (Adelaide)* 2:649-660.
- Somasini, S. and P. M. Huang. 1971. The nature of K- feldspars of a chernozemic soil in the Canadian prairies. *Soil Sci. Soc. Amer. Proceedings* 35:810-814.
- Smith, S. J., L. J. Clark and A. D. Scott. 1968. Exchangeability of potassium in soils. *Int. Congr. Soil Sci., Trans. 9th. (Adelaide)* 2:661-669.
- Smith, S. J., M. Liu, L. J. Clark and A. D. Scott. 1971. Interpretation of curves describing soil potassium exchange. *Soil Sci. Soc. Amer. Proceedings* 35:718-721.
- Stanford, G. 1948. Fixation of potassium in soils under moist conditions and on drying in relation to type of clay mineral. *Soil Sci. Soc. Amer. Proceedings* 12:167-171.
- Theisen, A. A. and M. E. Harward. 1962. A paste method for preparation of slides for clay mineral identification by X-ray diffraction. *Soil Sci. Soc. Amer. Proceedings* 26:90-91.
- Wear, J. I. and J. L. White. 1951. Potassium fixation in clay minerals as related to crystal structure. *Soil Sci.* 71: 1-14.
- Wentworth, Sally A. and N. Rossi. 1972. Release of potassium from layer silicates by plant growth and by NaTPB extraction. *Soil Sci.* 113:410-416.

APPENDIX I

Brief Morphological Description for the Soils Included
in This Study and Their Use

1) Quincy Series

The Quincy series consists of deep, somewhat excessively drained coarse-textured soils formed from wind-blown fine sand and loamy sand. Elevation ranges from 350 to 1,100 feet, and annual precipitation averages 7 to 9 inches. Mean annual temperature is 53 to 54°F, and the average growing season (32°) is 170 to 190 days. Native vegetation is mainly Indian ricegrass, needle-and-thread grasses, and rabbitbrush.

Representative profile: Quincy fine sand (moist colors)

0-60+'' Grayish brown, fine sand, loose, moderately alkaline.

Quincy soils are used for range. Low moisture-holding capacity and very severe wind erosion hazard are the main limitations for irrigation.

2) Ephrata Series

The Ephrata series, shallow, consists of shallow and very shallow, somewhat excessively drained soils formed in windblown, sandy material over basalt. Elevations range from 270 to 850 feet, and annual precipitation averages 7 to 8 inches. Mean annual air temperature is 54°F, and the average growing season (32°) is 180 days. The dominant native vegetation consists of sagebrush, bunchgrass, and rabbit brush.

Representative profile: Ephrata, sandy loam, shallow variant
(dry colors)

0-6'' Light brownish-gray, sandy loam, loose, mildly alkaline.

6-14'' Pale brown, sandy loam, loose, mildly alkaline.

14+" Basalt bedrock.

The shallowness of the soil and wide distribution of rock outcrop severely limit irrigation potential.

Ephrata soils are used for grazing, dryland wheat, and irrigated farming. High wind erosion hazard and low moisture-holding capacity are the major limitations.

3) Deschutes Series--Da

The Deschutes series consists of moderately deep, moderately coarse-textured, well drained soils formed mostly from pumice. Vegetation includes Indian ricegrass, needlegrass, bluebunch wheatgrass, Sandberg bluegrass, sagebrush, and rabbitbrush, with some juniper. Elevation ranges from 2,800 to 5,000 feet, and annual precipitation averages 8 to 12 inches. Mean annual air temperature is 46 to 48^oF, and the average growing season (32^o) is 70 to 100 days.

Representative profile: Deschutes sandy loam (moist colors)

0 to 13" Dark grayish brown sandy loam, very friable, neutral.

13 to 20" Dark brown sandy loam, firm, mildly alkaline.

20 to 28" Dark brown sandy loam, firm, moderately alkaline.

They are used for growing alfalfa, small grains, and potatoes under irrigation and for range where a source of water is not available. Depth and texture are the chief restrictions on irrigation potential. The temperature limitation is strong.

4) Poe Series (Po) (Tentative)

The Poe series consists of moderately deep, moderately well-drained soils formed in water-deposited sandy sediments, apparently derived from volcanic tuffs and basalt. Poe soils typically have very dark grayish brown, loamy fine sand surface layers overlying dark grayish brown similarly textured subsoils. They are underlain by strongly cemented hardpans at depths of 20 to 40 inches. The soil, including the hardpan, is commonly calcareous and ranges

from moderately to strongly alkaline throughout. A water table occurs at a depth of 2 to 3 feet during the irrigation season. Most areas are irrigated.

Poe soils occur at elevations of about 4,050 to 4,300 feet on nearly level bottomlands of Lost River and its tributary streams. Slopes range from less than 1 to 2 percent. Annual precipitation is 10 to 14 inches, and the frost-free season is about 90 to 120 days. The mean annual air temperature centers around 47°F.

Soils of the Poe series, except strongly alkaline areas, are used for pasture and to grow potatoes, alfalfa, and cereal grains. They are readily reclaimed by draining and proper irrigation. Deep ripping to eliminate the hardpan increases rooting depth and facilitates drainage and removal of sodium. A wind-erosion hazard exists in early spring.

5) Henley Series (Hn)

The Henley series is made up of moderately deep, somewhat poorly drained soils developed in sediments derived from volcanic tuff, basalt, diatomite, and small amounts of pumice ash. These soils typically have very dark grayish brown, very friable, loam surface layers and very dark gray subsoils of similar consistence and texture. A strongly cemented hardpan ranging from 2 to 20 inches thick occurs at depths of 20 to 40 inches. The entire soil, including hardpan, is characteristically strongly to very strongly alkaline.

Henley soils occur in the southern part of the Klamath Basin at elevations of 4,050 to 4,200 feet on nearly level bottomlands and low terraces. Slopes are less than 2 percent. Annual precipitation is 10 to 14 inches, and the frost-free season is about 90 to 120 days. The mean annual air temperature centers around 47°F.

Alkali, wetness, occasional overflow, and somewhat restricted depth are the major problems on Henley soils. These soils are principally used for irrigated pasture. Saltgrass is the major plant on unreclaimed areas. Drainage and ripping are needed for significant alkali reduction.

6) Metolius Series--Mt

The Metolius series consists of very deep, excessively drained soils derived from pumice alluvium on nearly level slopes. The native vegetation consists mostly of bunchgrasses, sagebrush, rabbitbrush, and some juniper. Elevation ranges from 2,600 to 3,600 feet, and annual precipitation is from 8 to 12 inches. Mean annual air temperature centers around 48°F and the average growing season (32°) is from 70 to 120 days.

Representative profile: Metolius sandy loam (dry colors)

0 to 14" Light brownish gray sandy loam, very friable, mildly alkaline, 11 to 20 inches thick.

14 to 22" Light brownish gray heavy sandy loam, very friable, moderately alkaline, 4 to 10 inches thick.

22 to 46" Light brownish gray and sandy loam, very friable, moderately alkaline, 10 to 30 inches thick.

46 to 49" Light brownish gray gravelly sand, loose, moderately alkaline.

Metolius soils are used for irrigated crops. The climatic limitation is moderate to strong.

7) Madras Series--Ma

The Madras series consists of moderately deep, well drained soils derived from old water-laid materials of the Dalls formation on nearly level to moderate slopes. The native vegetation consists of bunchgrasses, big sagebrush, rabbitbrush, scattered juniper, and associated herbs. Elevations range from 2,000 to 3,500 feet, and average annual precipitation is from 9 to 11 inches. Mean annual air temperature centers around 47°F, and the average growing season (32°) is from 70 to 120 days.

Representative profile: Madras loam (dry colors)

- 0 to 8" Light brownish gray loam, very friable, slightly acid,
6 to 8 inches thick.
- 8 to 11" Grayish brown loam, friable, neutral, 2 to 6 inches thick.
- 11 to 17" Brown clay loam, firm, mildly alkaline, 6 to 10 inches
thick.
- 17 to 20" Pale brown gravelly loam, friable, moderately alkaline,
2 to 4 inches thick.
- 20 to 25" Light yellowish brown medium-textured hardpan, 5 to 20
inches thick.
- 25"+ Semi-consolidated tuffaceous sandstone.

Madras soils are used for dryland farming, irrigation, and range. The climatic limitation is strong.

8) Agency Series--Ag

The Agency series consists of moderately deep, well drained soils formed in medium-textured deposits of volcanic origin. Slopes are nearly level to very steep. Native vegetation is big sagebrush, bluebunch wheatgrass, Idaho fescue, and Sandberg bluegrass. Elevation ranges from 2,200 to 4,400 feet, and annual precipitation averages 8 to 10 inches. Mean annual air temperature is 47 to 49°F, and the average growing season (32°) is 60 to 110 days.

Representative profile: Agency loam (moist colors)

- 0 to 10" Very dark grayish brown loam, friable, neutral.
- 10 to 20" Dark brown clay loam, firm, mildly alkaline.
- 20 to 28" Dark brown clay loam, firm, moderately alkaline.
- Below 28" Lime-coated basalt.

They are used for dryland small-grain production and range. Irrigation suitability varies from good to poor, depending on slope.

9) Nyssa Series (Ny)

The Nyssa series consists of moderately deep, well-drained soils with a weakly cemented pan formed on higher terraces along the Snake River underlain by lacustrine materials or old alluvium and mantled by thin loess. The terraces are dominantly gently sloping but range to steeply sloping where dissection has occurred. The native vegetation consists mostly of bluebunch wheatgrass, Thurber's needlegrass, *Atriplex* spp., and big sagebrush. Elevations range from 2,200 to 2,500 feet. Average annual precipitation is from 7 to 9 inches, and mean annual air temperature centers around 52°F. The average growing season (32°) is from 150 to 180 days.

Representative profile: Nyssa silt loam (dry colors)

- 0-30" Pale brown silt loam, friable, mildly to moderately alkaline. Twenty to thirty inches thick.
- 30-40" White nodular silt loam, with weakly cemented laminations extremely hard, moderately alkaline. Ten to eighteen inches thick.
- 40-66"+ Light brownish gray stratified very fine sandy loam and silt loam, friable, moderately alkaline.

Nyssa soils are associated with Nyssaton soils. Nyssa soils are used mostly for irrigated row crops and for range. They have a high potential for range seeding and are well suited for irrigation. The temperature limitation is slight to moderate.

Appendix II Table 1. Water, ammonium acetate and HNO₃ extractable potassium from triplicate subsamples of each soil.

Soil Series	H ₂ O				NH ₄ OAc				HNO ₃			
	R ₁	R ₂	R ₃	\bar{R}	R ₁	R ₂	R ₃	\bar{R}	R ₁	R ₂	R ₃	\bar{R}
	μg/gm											
Quincy	25	36	30	30	260	250	240	250	1080	1081	1082	1081
Ephrata	42	43	44	43	350	353	356	353	1366	1366	1366	1366
Deschutes	6	10	8	8	140	135	139	138	556	555	557	556
Deschutes	18	18	18	18	250	249	257	253	730	728	729	729
Poe	30	36	46	37	317	317	137	137	1000	1002	1001	1001
Poe	56	57	58	57	419	417	415	417	1180	1178	1182	1180
Poe	94	86	90	90	720	716	718	718	2002	2003	2004	2002
Henley	108	110	114	111	1380	1384	1388	1384	3449	3450	3448	3449
Metolius	34	36	36	35	305	306	304	305	975	975	975	975
Madras	34	49	50	47	344	344	344	344	1130	1130	1131	1130
Agency	64	62	60	62	425	429	427	427	1420	1421	1420	1420
Madras	68	58	74	67	459	460	458	459	1409	1411	1410	1410
Madras	76	88	94	86	625	623	624	624	1795	1797	1492	1794
Nyssa	28	34	30	31	513	513	513	513	1850	1860	1858	1856
Nyssa	41	41	43	42	605	607	606	606	2230	2234	2232	2232

Appendix II Table 2. Ammonium acetate and HNO₃ extractable potassium from triplicate subsamples of the clay fractions.

Soil Series	NH ₄ OAc				HNO ₃			
	R ₁	R ₂	R ₃	\bar{R}	R ₁	R ₂	R ₃	\bar{R}
	μg/gm							
Quincy	4000	4003	3997	4000	14405	14400	14395	14400
Ephrata	4250	4250	4251	4250	13049	13051	13050	13050
Deschutes	1200	1200	1201	1200	4802	4800	4798	4800
Deschutes	2250	2260	2255	2255	5700	5700	5700	5700
Poe	1999	2000	2001	2000	5714	5714	5713	5714
Poe	2125	2125	2125	2125	6200	6202	6197	6200
Poe	2908	2912	2910	2910	8307	8310	8313	8310
Henley	5065	5067	5069	5067	12230	12236	12233	12233
Metolius	1115	1115	1114	1115	3346	3346	3346	3346
Madras	1070	1072	1071	1071	3285	3286	3287	3286
Agency	1350	1353	1356	1353	3618	3621	3621	3620
Madras	1344	1344	1343	1344	3430	3431	3431	3431
Madras	1410	1412	1414	1412	3825	3825	3822	3824
Nyssa	1306	1305	1307	1306	3885	3894	3888	3889
Nyssa	1542	1542	1541	1542	5132	5132	5131	5132

Appendix II Table 3. Ammonium acetate and HNO₃ extractable potassium from triplicate subsamples of silt fractions.

Soil Series	NH ₄ OAc				HNO ₃			
	R ₁	R ₂	R ₃	\bar{R}	R ₁	R ₂	R ₃	\bar{R}
	μ g/gm							
Quincy	651	650	650	650	5350	5351	5350	5350
Ephrata	863	864	865	864	6101	6100	6099	6100
Deschutes	304	306	308	306	1442	1445	1443	1444
Deschutes	384	384	384	384	1547	1548	1546	1547
Poe	500	501	500	500	2175	2175	2175	2175
Poe	620	628	624	624	2470	2472	2471	2471
Poe	980	984	982	682	3800	3802	3799	3800
Henley	1740	1739	1741	1740	5495	5496	5497	5496
Metolius	280	280	280	280	1328	1332	1330	1330
Madras	255	259	257	257	1386	1393	1388	1389
Agency	240	240	241	240	1408	1412	1411	1410
Madras	285	289	286	287	1440	1441	1441	1441
Madras	300	296	298	298	1960	1966	1962	1963
Nyssa	352	352	352	352	1540	1542	1547	1543
Nyssa	401	403	402	402	1730	1730	1729	1730

Appendix II Table 4. Ammonium acetate and HNO₃ extractable potassium from triplicate subsamples of sand fractions.

Soil Series	NH ₄ OAc				HNO ₃			
	R ₁	R ₃	R ₃	\bar{R}	R ₁	R ₂	R ₃	\bar{R}
	μg/gm							
Quincy	40	40	38	39	92	90	93	92
Ephrata	45	46	49	47	145	147	150	147
Deschutes	20	19	19	19	52	52	51	52
Deschutes	32	34	33	33	94	93	92	93
Poe	55	55	54	55	178	176	180	178
Poe	76	78	77	77	146	150	149	148
Poe	177	176	175	176	345	347	349	347
Henley	295	295	294	295	620	623	626	623
Metolius	70	71	70	70	175	175	175	175
Madras	103	104	105	104	260	262	264	262
Agency	133	132	133	133	544	540	548	544
Madras	133	133	133	133	500	500	499	500
Madras	198	200	202	200	520	525	530	525
Nyssa	173	172	173	173	864	860	868	864
Nyssa	125	125	126	125	788	790	790	790

APPENDIX III

Criteria for Identification of Clay Minerals

The criteria for identification of phyllosilicates by X-ray diffraction (Brown, 1961; Harward and Brindly, 1965; Sayegh, Harward and Knox, 1965; Harward, Carstea, and Sayegh, 1969) are as follows:

Approximation 001 Spacings (\AA)^o Obtained by Characterization Treatments

Treatment	Minerals Identified*					
	K ¹	S ²	V	M ³	C ⁴	CT ⁵
Mg-sat.; 54% R.H.	7.2-7.5	15.3	14.3	9.9-10.4	14.2	14-15
Mg-sat., Eth. Glycol.	"	16.9	14.2	"	"	14-17
Mg-sat., Glycerol	"	17.4	14.1	"	"	14-17
K-sat.; 105 ^o C; Dry air	"	10.3	10.3	"	"	14
K-sat.; 54% R.H.	"	12.1-12.4	10.4	"	"	14
K-sat., 300 ^o C; Dry air	"	9.9-10.4	10.2	"	"	11-14
K-sat., 550 ^o C; Dry air	-	9.8-10.2	10.0	"	"	10-13

* K = Kaolin, S = Smectites, V = vermiculite, M = micas, C = chlorite, CI = chloritic intergrades.

¹ Presence of 7.2-7.5 component regardless of saturation cation, humidity or solvation. Well crystallized kaolinite has 001 spacing of 7.15 with sharp peaks. Halloysite exhibits spacings of 7.5-7.5 which may expand slightly on rehydration or solvation; the peaks are normally broader than for kaolinite. At 550^oC Kaolins lose hydroxyl groups and the crystal structure disintegrates.

² Beidellite essentially has the same spacings as montmorillonite except that expansion to duo-interlayer complex does not occur with glycerol vapor.

³ Presence of 9.9-10.4 \AA ^o component regardless of saturation cation, humidity or solvation.

⁴ A 14 \AA ^o spacing does not vary with solvation or potassium-saturation and heating.

⁵ Properties are intermediate between chlorite and vermiculite or smectite. The predominant feature is resistance to collapse upon potassium-saturation and heating. As amount and stability of hydroxyinterlayers increases, the lattice is more difficult to collapse. Samples toward the chlorite end of the spectrum may also exhibit resistance to expansion upon solvation.