THE RELEASE OF EXCHANGEABLE AND NONEXCHANGEABLE POTASSIUM FROM SEVERAL WESTERN OREGON SOILS

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF THE LITERATURE	3
EXPERIMENTAL METHODS	17
Soil Sampling Procedure	17
Greenhouse Procedure	19
Laboratory Procedure	24
RESULTS	26
Greenhouse Trial	26
Randomly Selected Soil Samples	42
Profile Samples	53
DISCUSSION	64
Greenhouse Trial	64
Randomly Selected Soil Samples	69
Profile Samples	70
SUMMARY AND CONCLUSIONS	73
BIBLIOGRAPHY	77
APPENDIX	82

LIST OF FIGURES

		Page
Figure 1.	Relationship between the K released from twenty soils by ten successive cuttings of clover in the greenhouse and the K released by 1.0 normal HNO_3	31
Figure 2.	Relationship between the K removed from twenty soils by ten successive cuttings of clover in the greenhouse and the K released by 1.0 normal HNO_3	32
Figure 3.	Relationship between the K removed from twenty soils by ten successive cuttings of clover in the greenhouse and the total K extracted by boiling 1.0 normal HNO_3	33
Figure 4.	Relationship between the K removed from twenty soils by ten successive cuttings of clover in the greenhouse and the exchangeable K before cropping	34
Figure 5.	Relationship between the K released from twenty soils by ten successive cuttings of clover in the greenhouse and the exchangeable K before cropping	35
Figure 6.	Relationship between the K removed by six successive cuttings of clover from twenty soils in the greenhouse and the total K extracted by boiling 1.0 normal HNO_3	37
Figure 7.	Relationship between the K removed from twenty soils by three successive cuttings of clover in the greenhouse and the exchangeable K before cropping	38
Figure 8.	Relationship between the decrease in exchangeable K during cropping and the percent-base saturation with K before cropping	39
Figure 9.	Relationship between the percent K removed by cropping coming from moderately available forms and the exchangeable K before cropping	40
Figure 10.	Relationship between the K released from twenty soils by boiling normal HNO_3 and exchangeable K before cropping	41

LIST OF FIGURES continued

		Page
Figure 11.	Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract with depth in soil samples from randomly selected sites in Western Oregon	46
Figure 12.	Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract with depth in soil samples from randomly selected sites in Western Oregon	47
Figure 13.	Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract in three Powell profiles	57
Figure 14.	Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract in a Cascade profile	58
Figure 15.	Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract in a Dayton and a Cascade profile	59
Figure 16.	Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract in Viola and Amity profiles	60
Figure 17.	Distribution of exchangeable K, K released by HNO_3 and total K in HNO_3 extract in an Amity and a Willamette profile	61

LIST OF TABLES

		Page
Table I	Soil type, great soil group, parent material, drainage, location by county, and cultural status of 20 soils used in greenhouse study	21
Table II	Some chemical properties of 20 soils used in the greenhouse study	22
Table III	Change in exchangeable K during growth of ten cuttings of clover in the greenhouse, the calculated release of K from nonexchangeable forms, and sources of K taken up by the clover	27
Table IV	Exchangeable K before and after cropping and K extracted by HNO_3 for 20 soils used in greenhouse study	28
Table V	Linear correlation coefficients for the relationships between K extracted from 20 soils by cropping and K extracted by chemical methods	30
Table VI	Exchangeable K in soil samples from 100 randomly selected sites - each figure represents an average for ten sites	43
Table VII	K released from nonexchangeable forms by HNO_3 in soil samples from 100 randomly selected sites - each figure represents an average for ten sites	44
Table VIII	Total K in HNO_3 extract in soil samples from 100 randomly selected sites - each figure represents an average for ten sites	45
Table IX	Percentage of soil samples from 100 randomly selected sites classified as low, medium and high in exchangeable K and K released by HNO_3	48
Table X	Linear correlation coefficients for indicated relationships between soil samples from randomly selected sites	52
Table XI	Exchangeable K, K released from nonexchangeable forms by HNO_3 and total K in HNO_3 extract in profile samples (K expressed in PP2M)	55

LIST OF TABLES continued

		Page
Table XII	Principal morphological characteristics of the horizons of eleven profiles	83
Table XIII	Yield of clover at different harvests - grams dry matter per can	87
Table XIV	Percent K in clover at different harvests	88
Table XV	Cumulative uptake of K in greenhouse trial - PP2M	89

THE RELEASE OF EXCHANGEABLE AND NONEXCHANGEABLE POTASSIUM
FROM SEVERAL WESTERN OREGON SOILS

INTRODUCTION

The potassium supplying power of a soil has been defined as its ability to supply potassium to growing plants from both the exchangeable and moderately available forms.

Most soils contain an abundant amount of potassium, however, only a small percentage of the total is present in the exchangeable and moderately available forms. Results of numerous investigations show that soils vary considerably in their potassium supplying power. The reasons for this variation are not completely understood. Type of clay minerals, degree of weathering, and the amount and kind of potassium bearing minerals appear to influence the capacity of a soil to release potassium from nonexchangeable to exchangeable forms.

Long time cropping in the greenhouse has been used extensively in the past to determine the potassium supplying power of soils. This method is very time consuming and also quite costly. More recently it was found that the amount of potassium released from nonexchangeable forms by such laboratory procedures as boiling with nitric acid and incubation with exchange resins was highly correlated with the amount of potassium released from nonexchangeable forms by greenhouse cropping.

Results of investigations conducted on soils in different areas in the United States are not in agreement as to the reliability of exchangeable potassium as an index to the release of potassium from nonexchangeable forms during greenhouse cropping. Some investigators found a high correlation between these two values while others found a very low correlation.

Most of the previous studies dealing with potassium in Oregon soils have been limited to the exchangeable potassium content of the soils. With increasing use of nitrogen, phosphorus and lime, which in turn result in higher yields and more potassium being removed from the soil, more and more soils are beginning to analyze low in exchangeable potassium. The question then arises do these soils release potassium at a rate which is adequate to meet the need of the crop plants? It appears desirable to determine the potassium supplying power of these soils in order to discover those soils and those areas which now need potash fertilizer or may need them in the not too distant future.

The purpose of this study was to:

1. Determine the potassium supplying power of several Western Oregon soils.
2. Evaluate exchangeable potassium, potassium released from nonexchangeable forms by boiling nitric acid, and total potassium extracted by the boiling acid as indexes to the removal of potassium from these soils by greenhouse cropping.
3. Determine variations in the potassium status within a soil series, between soil series, and between certain areas in Western Oregon.

REVIEW OF THE LITERATURE

Potassium is usually the most abundant of the major and secondary nutrient elements in the soil. Reitemeier (42, pp. 404-405), in reviewing the literature on potassium, stated that the range of total potassium content of soils is enormous. Some soils have been found to contain as much as 5.15 per cent K_2O while others contain only a trace. These values are both extremes and the bulk of the values for total potassium will fall somewhere in between.

In soils which have not had potash fertilizer applications, the proportion of the total held in soluble and releaseable forms is usually very small. The majority of it is found in potassium-bearing primary and clay minerals. The primary silicate minerals high in potassium are muscovite, biotite, orthoclase and microcline; but other micas, feldspars and other minerals may contain considerable amounts of potassium. Of the clay minerals the illite group which includes the entire range of hydrous micas, is considered to be the only one containing substantial amounts of potassium.

The various forms of soil potassium are related and comprise a system in which an increase in one form occurs at the expense of one or more of the other forms and in which the net movement may occur from less available to highly available forms, or the reverse depending upon the particular stress. The availability to plants depends on the amount and relative mobility of the different forms, including the rate of replenishment of depleted immediately available forms by release from reserve supplies.

Wood and DeTurk (56, pp. 152-153), indicated that the potassium equilibrium of any soil can be represented as follows:

Primary mineral $\longrightarrow$ fixed K (Acid insoluble K $\rightleftharpoons$ Acid soluble K) $\rightleftharpoons$ replaceable K $\rightleftharpoons$ water soluble K.

The removal of potassium from either of the last three forms would cause displacement of the equilibrium to the right. Little change will occur in the first form except over geological time.

It long has been known that the exchangeable and water soluble potassium of soils which have not received potash fertilizers could not possibly be sufficient for crop production over long periods of time. Before the advent of the concept of base exchange in soils, the immediate source of potassium was attributed to the breakdown of minerals. It is only comparatively recently that the interrelation of exchangeable and released nonexchangeable potassium as they affect availability to plants have been extensively investigated.

In 1933, Hoagland and Martin (21, pp. 29-30) conducted an experiment to determine the potassium supplying power of 15 California soils. Barley and tomato plants were grown as indicator crops. The soils were subjected to continuous cropping for several years in order to exhaust the supply of available potassium. They were concerned with the availability of three forms of potassium to the plants, namely exchangeable, nonexchangeable and soil solution potassium. Two important conclusions were made as a result of this investigation. One was that the exchangeable potassium drops to a minimum level after repeated cropping and goes no lower. It was noted that the minimum level was the same for several soils regardless of the initial levels of exchangeable potassium. The second conclusion was that the per cent of potassium in the plant from nonexchangeable sources increased as the level of exchangeable potassium decreased. They also found that the soils differed widely in their ability to supply native potassium to the plants.

A currently common method of measuring the relative ability of release of different soils is that of prolonged cropping; either by successive cuttings of one planting of one crop, by repeated plantings of one crop, or by a succession of different crops. A variety of experimental conditions such as plant species, plant population, quantity of soil, length of cropping period, effect of lime, and effect of potash additions have been used.

Abel and Magistad (1, pp. 452-454) intensively cropped several Hawaiian soils and found that they released about 100 pounds of K_2O per acre foot of nonexchangeable potassium annually.

Bear, Prince and Malcolm (9, pp. 146-149) grew seven crops of alfalfa on twenty New Jersey soils and found that the level of exchangeable potassium was a good criterion for release of potassium to the crop and that total potassium was not.

Chandler et al. (13, pp. 715-721) concluded that in order to predict the potassium supplying power of the soil, the equilibrium level of the exchangeable potassium for that particular soil must be known. They found that with continuous cropping the exchangeable potassium level dropped to a certain value and did not decrease with additional cropping. They also noted that soils with the same level of exchangeable potassium before cropping varied considerably in their ability to release potassium from nonexchangeable forms.

Stewart and Volk (50, pp. 270-272) also found that certain Alabama soils varied widely in release of potassium from nonexchangeable forms upon continuous cropping in the greenhouse. The amount released appeared to be the dominant factor in the potassium nutrition of the plants. They saw no relationship between the amount of potassium removed from the soil by cropping and the amount of exchangeable potassium or total potassium.

Gholston and Hoover (19, pp. 120-121) studied the potassium supplying power of several Mississippi and Alabama soils and found marked differences in the rate of release of nonexchangeable potassium to millet grown in the greenhouse for 454 days. They did not offer any explanation for these differences.

In 1950, Breland, Bertramson and Borland (11, pp. 240-246) determined the potassium supplying power of twenty three major soil types in Indiana. They grew Ladino clover in the greenhouse continuously for 493 days and took eight cuttings. Their results indicated that the exchangeable potassium level after three cuttings was closely correlated with the amount of potassium released to the plants from nonexchangeable forms. The original exchangeable potassium, however, was not related to the amount released to the clover. They found that the soils varied considerably in their potassium supplying power and stated that the ability of different soils to release potassium from the nonexchangeable to the exchangeable forms for plant consumption appeared to be a dominant factor in the nutrition of plants and was a characteristic of each soil type.

Pratt (36, pp. 112-117) grew alfalfa in the greenhouse on thirteen Iowa soils for ten months. He found that exchangeable potassium at the beginning of the cropping period was a reliable index to the removal of potassium from the soils during the cropping period. The correlation coefficient between these two values was 0.97.

Pearson (32, pp. 308-309) continuously cropped eight Alabama soils and concluded there was no relationship between exchangeable potassium before cropping and the amount of potassium released during cropping. He did find, however, that the original exchangeable potassium was highly correlated with the total amount of potassium removed from the soils during the cropping period.

Numerous other investigations have been conducted to determine the potassium supplying power of various soils by intensive greenhouse cropping. Some of these were: Alban (2, pp. 1-69), Attoe and Truog (4, pp. 81-86), Ayers et al. (8, pp. 175-181), Bray and DeTurk (10, pp. 101-106), Evans and Attoe (15, pp. 323-334), Kolodny and Robbins (28, pp. 303-313), and Reitemeier et al. (39, pp. 158-162). The results of these investigations were not consistent. Some investigators found that the original exchangeable potassium was highly correlated with the potassium removed by the plants and with the potassium released from nonexchangeable forms during cropping. Others found that exchangeable potassium before cropping was not a reliable index either to the amount of potassium removed by the crop or released from nonexchangeable forms during cropping.

Pratt (36, pp. 115-116) reasoned that the difference in results obtained by the various investigators with respect to the exchangeable potassium as an index to potassium removed by cropping and to potassium release during cropping could possibly be rationalized by a consideration of the soil conditions involved. Where exchangeable potassium served as a good criterion of the potassium released to crops over a long cropping period the soils were not strongly weathered. On the other hand, where exchangeable potassium was a poor criterion of potassium release to crops, the soils had been moderately to strongly weathered. He postulated that the exchangeable potassium in strongly weathered soils is so low that for a given extended cropping period the proportion of potassium used by the plants from the nonexchangeable forms was much higher than in only slightly weathered soils where the exchangeable potassium is high. There would be more reason, therefore, to expect the exchangeable potassium to be highly correlated with potassium uptake by plants in soils similar to the Iowa soils he studied than in the more highly weathered soils studied by Breland, Bertramson and Rouse (11, pp. 237-247), Rouse and Bertramson (43, pp. 113-123) and Stewart and Volk (50, pp. 263-272).

Reitemeier (42, pp. 124) lists some of the general principles which have emerged from the various studies of the release of nonexchangeable potassium during cropping as follows:

1. Broad differences exist among the capacities of different soils to release nonexchangeable potassium of native origin.

2. Soils containing equal amounts of total potassium differ considerably in the availability of reserve potassium.

3. Fixed potassium is generally more available than native non-exchangeable forms.

4. Although release from some soils occurs when the exchangeable potassium level is relatively high, it is more likely to occur at the lower levels provided that the vigor of the plants is not drastically reduced thereby.

5. The initial level of exchangeable potassium is not an accurate index of reserve supplying power unless it represents the equilibrium level of the particular soil.

6. If the intensity and period of cropping is sufficient, the exchangeable potassium is reduced to a minimum value and all subsequent release occurs at this exchange level--this is not as likely to occur in the field as in small containers.

7. Plants absorb more reserve potassium than is liberated to the exchangeable form in the absence of plants during moist storage for the same period of time.

Since long-time cropping in the greenhouse is a very time-consuming method, some of the more recent investigations were designed to develop other methods which would measure the release of potassium from non-exchangeable forms in a shorter period of time. Some of the methods which have been used are: the Neubauer seedling method, extraction of the soil with strong acids, electrodialysis, and incubation with exchange resins.

Many investigators, including Olsen and Shaw (30, pp. 6-7) have used the Neubauer test for determining the availability of potassium to plants. Reitemeier, Holmes, and Brown (40, pp. 102-105) reduced the amount of soil used in the Neubauer test from 100 to 25 grams for a group of soils from the Great Plains and thereby increased the rate of release and the differential between soil samples.

These same authors (41, pp. 33-39) determined the amount of potassium released by the Neubauer procedure, extraction with boiling, 1.0 normal nitric acid and electrodialysis. They found that the correlation coefficient between Neubauer release and that released by 740 days of cropping with Ladino clover was 0.897. The correlation coefficient for the relationship between potassium release during cropping and that released by 30 days of electrodialysis was 0.964. The amount of potassium released by boiling nitric acid was also highly correlated with the amount released by greenhouse cropping with Ladino clover (0.938).

Rouse and Bertramson (43, pp. 118-120) obtained a correlation coefficient of 0.96 for the relationship between the potassium released by boiling nitric acid and that released by greenhouse cropping of several Indiana soils with Ladino clover.

In 1951, Pratt (36, pp. 111-115) found that this relationship held for the Iowa soils he studied. The correlation coefficient between potassium released to nitric acid and that released by intensive cropping with alfalfa was found to be 0.913. The total potassium in the nitric acid extract was also highly correlated with the total potassium removed from thirteen Iowa soils during the cropping period (0.965). He also obtained a correlation coefficient of 0.963 between the potassium released during greenhouse cropping and that released during incubation with a Dowex exchange resin.

Schmitz (45, pp. 30-35) studied the behavior of potassium in several Ohio soils. His results also showed a high correlation between the potassium released to nitric acid and that released during intensive greenhouse cropping with corn and also between the total potassium extracted by the acid and the amount removed by the corn during the cropping period, the former coefficient being 0.955 and the latter 0.784. The correlation coefficient between the potassium released by cropping and that released by incubation with an Amberlite exchange resin was 0.882.

Pratt and Morse (38, pp. 15-20) recently determined the potassium release by boiling nitric acid from a number of Ohio soils. Their results indicated that potassium release from nonexchangeable forms was more a characteristic of the soil type and the soil area than was the exchangeable potassium. The correlation between exchangeable potassium and potassium release was not high. Exchangeable potassium in the 0-6" depth was not highly correlated with exchangeable potassium in the 6-12" depth, while the potassium released in the 0-6" depth was highly correlated with that released in the 6-12" depth.

Prior to 1949 most of the research on the release of potassium by prolonged cropping and other methods was concerned only with the relative amounts of potassium released by different soils. At this time several papers appeared which reported on the results of experiments designed to ascertain the source of the potassium supplying power of the soil.

In a study using this approach, Rouse and Bertramson (43, pp. 120-

123) found that most of the nonexchangeable potassium was released from the silt and clay fractions. They also studied the relationship of the release of nonexchangeable potassium from the different size soil fractions with the mineralogical composition of the fraction. X-ray diffraction patterns were obtained on the several size fractions. There was no apparent relationship between the potassium released by boiling nitric acid and the mineralogical composition of the courser fractions. However, for the two smaller fractions 2 micron and 0.2 micron, they obtained a high correlation coefficient between the area under the illite peak and the release of nonexchangeable potassium from these fractions.

In another study Pratt (37, pp. 26-29) fractionated several Iowa soils and found that the delivery of potassium to nitric acid was highest in the 0.2-2u fraction for twelve of the thirteen soils studied. He pointed out that the release of nonexchangeable potassium to nitric acid from the silt fraction when compared to the release from the clay fraction for the same soil could be used as a criterion to the degree of weathering for the soils under study. When the soils derived from loess were arranged according to this criterion they were found to follow a weathering sequence.

Phillippe and White (34, pp. 171-172) studied the potassium supplying power of several Indiana soils as related to their content of potash bearing minerals. They found a relationship existed between the release of potassium from nonexchangeable forms and the microcline content of the soils.

Reitemeier, Holmes and Brown (41, pp. 40-41) determined the clay mineral composition of the 2-micron clay fraction of six soils by a combination of methods, namely, x-ray diffraction spectrogram, differential thermal analysis, cation exchange capacity and potassium content. The hydrous mica content, disregarding the occurrence of quartz and amorphous materials, was estimated to range from 60% to 90%. They concluded that no explanatory relationship was established between the general order of potassium supplying capacity and other properties that were determined, such as initial exchangeable potassium, total potash content of the soil, silt or clay, abundance of silt, clay, or organic matter, content of potassium-bearing minerals in the silt fraction, and the hydrous mica content of the 2-micron clay fraction. They suggested that since differences between soils with respect to their availability of nonexchangeable potassium must lie in their mineralogical characteristics, that the usual methods of estimating mineral contents must be supplemented by determination of the actual potassium content and behavior of minerals as they exist in soils.

Another phase of the equilibrium of the various forms of potassium in the soil has received considerable attention. This concerns the fixation of available potassium to less available forms and also the release of nonexchangeable potassium from moderately available to available forms by such mechanisms as freezing and thawing, alternate wetting and drying and moist storage. Among those conducting experiments along this line were Attoe (6, pp. 145-149) 7, pp. 112-113), Fine, Bailey and Truog (17, pp. 183-186), Hoover (23, pp. 66-71), Joffe and Levine (26, pp. 411-420), Kolodny and Levine (28, pp. 303-313), Stanford (49, pp. 123-129), Volk (52, pp. 263-272) and Wear and White

(54, pp. 1-4).

Some of the concepts arising from the results of these investigations are as follows: Potassium fixation occurs when an excess of exchangeable potassium is present. The three general types of clay minerals act differently. Minerals with 2:1 expanding lattices, such as montmorillonite, fix potassium only by lattice contraction. To fix potassium they must be dehydrated by drying or some such process. Minerals with 2:1 nonexpanding lattices, such as illite, fix potassium either upon dehydration or in the moist state. Potassium fixation by these minerals is believed to be due to their relatively high number of tetrahedral forces as opposed to octahedral forces. Minerals with 1:1 nonexpanding lattices such as kaolinite do not fix potassium under either moist or drying conditions.

Bray and DeTurk (10, pp. 102-105) found that under conditions of moist storage and of drying at 200° C., Illinois soils would decrease or increase in exchangeable potassium content depending on whether the initial exchange level was relatively high or low; different soils had characteristic levels which they would tend to approach from either direction.

In determining the effect of freezing and thawing on soil potassium, Fine, Bailey and Truog (17, pp. 184-185) observed in a study of twelve soils that eight of them increased in exchangeable potassium as much as 150 pounds per acre, one remained the same and three showed a decrease.

It is apparent, therefore, that the equilibrium of the various forms of potassium in the soil is very complex and dependent on a variety of factors.

In the past there has been some confusion resulting from the terminology utilized by various investigators in connection with the different forms of soil potassium. In 1949, the Soil Science Society of America's Committee on Terminology (24, pp. 404-405) defined some of these terms and recommended that the following terminology be used in future publications.

Exchangeable potassium

The potassium which is held mainly by the colloidal portion of the soil and which is easily exchanged with the cations of neutral salt solutions, less the water-soluble potassium. It is readily available to growing plant roots.

Nonexchangeable potassium

All of the potassium in the soil except the exchangeable and water-soluble potassium.

Moderately-available potassium

The potassium in the soil which cannot be readily exchanged with cations of a neutral salt solution but which will move into the exchangeable form by equilibrium as the exchangeable form is depleted.

Potassium fixation

The process of converting exchangeable or water-soluble potassium to moderately available potassium.

<u>Fixed potassium</u>

Exchangeable or water-soluble potassium which has been transformed to moderately available potassium.

<u>Potassium-supplying power of soils</u>

The capacity of a soil to supply potassium to growing plants from both exchangeable and moderately-available forms.

EXPERIMENTAL METHODS

This study consisted of two main phases. One was a greenhouse trial to determine the potassium supplying power of soils from twenty sites in Western Oregon and to determine the relationship between potassium removal and release by greenhouse cropping, total potassium extracted and potassium release by nitric acid, and exchangeable potassium before cropping.

The other phase dealt with a survey of the potassium status of soils from 100 randomly selected sites in Western Oregon by obtaining values from exchangeable potassium and for potassium release from non-exchangeable forms by extraction with nitric acid.

In addition, profile samples from eight sites in Multnomah and Columbia counties were studied. Duplicate samples from these sites were sent to the Soil Survey Laboratory, Soil Conservation Service, U.S.D.A. for certain mineralogical and chemical determinations.

Soil sampling procedure

Random samples: Soil samples from 100 randomly selected sites and representing six soil series were collected from cropped land in the fall of 1953.

The random sampling procedure follows. Extensive areas of the soils included in the survey were selected according to the delineations appearing on existing soil maps. The boundaries of these areas were plotted on county road maps with a scale of 1 inch to the mile. All roads passing through each of these areas were listed, beginning with north-south roads from west to east, and then all west-east roads from north to south. The length of each road within that body of soil was recorded and the total length of all roads within the same body of soil determined.

Using (0.1), one tenth of a mile as a unit of measurement, and a three place table of random numbers, 25 numbers were selected. Using a predetermined starting place, 25 sites were then located in each major area. The first 10 numbers were labeled regular sampling sites and the remaining 15 as alternate sites. All sites were at least 0.2 miles apart.

The side of the road on which the samples were collected was determined by using a random number table and letting the odd numbers represent the left side of the road and the even numbers the right side of the road.

After reaching the site marked on the map, a point 300 feet from the road and at right angles to the road was located. Using this point as the center of a circle from a 20 foot radius, three subsites were located on the circumference of this circle about 120 degrees apart. At each subsite, four cores (1 inch diameter) for each of the 0-6", 6-12", and 12-18" depths were taken with an Oakfield tube sampler, and the 12 cores representing each depth were composited.

If any of the regular sampling sites proved inadequate due to such factors as not being cropped or varying too much from the soil type mapped, the nearest alternate site was substituted.

Profile samples: In the fall of 1953 duplicate profile samples from eight uncropped sites, four each in Columbia and Multnomah counties, were collected. Three of these sites were in areas mapped Powell, 2 in Cascade, 2 in Viola and 1 in an area mapped Amity. The sites for these samples were selected by Mr. J. M. Williams, Soil Survey Supervisor for Western Oregon with Soil Conservation Service, U.S.D.A. After the pits were opened, Mr. Ray C. Roberts, Principal Soil Correlator, Far Western States, Soil Conservation Service, U.S.D.A., collected duplicate samples by horizon and also wrote up detailed profile descriptions for each site. One set of the samples was sent to the Soil Conservation Service Laboratory in Beltsville, Maryland for mineralogical analysis of the clay fraction and certain chemical analyses of the whole soil. The other set of samples was taken to Corvallis for determination of exchangeable potassium and potassium release from nonexchangeable forms by extraction with nitric acid. Profile descriptions are given in Table XII of the appendix. In addition, profile samples from one site each of Amity and Willamette in Benton County and one site of Dayton in Linn County were collected. Only single samples of each horizon were taken and exchangeable potassium and releaseable potassium determined. No mineralogical studies were made on these profiles.

Greenhouse procedure

Soil samples from 20 sites in Benton, Columbia, Linn, Multnomah, and Washington counties, all in Western Oregon, were collected in the spring of 1954. All samples, with the exception of one Dayton subsurface sample (13-24"), were surface soils (0-6"). Exchangeable potassium and acid releaseable potassium were determined on 50 samples representing a cross section of the 100 randomly selected samples collected in the fall of 1953 from the same area and on the surface horizons of the profile samples. On the basis of these analyses 20 sites, which represented a wide range in both exchangeable and acid releaseable potassium as well as cropped and uncropped conditions were selected for the greenhouse trial. Table I presents the soil type, parent material, great soil group, and cultural status of these soils. Table II lists certain of their chemical characteristics.

Bulk samples were brought into the greenhouse, air dried, screened and thoroughly mixed. Five pounds of soil (oven-dry basis) were then placed in No. 10 enameled tin cans having a one half inch layer of sand on the bottom. Prior to placing the soils in the cans, 1500 pounds per acre* of 20 per cent superphosphate and enough c.p. $CaCO_3$ to satisfy the lime requirement, were thoroughly mixed with the soil. In addition, minor elements in the amounts used by Breland et al. (11, pp. 238-239) were added in solution. After the fifth harvest an additional 150 pounds of P_2O_5 per acre in the form of a dilute solution of phosphoric acid was added to the soil. A randomized block design with six replications was used in this trial. Each table had four rows of ten cans representing two replications. Border rows of cans were placed on each end of the tables and the inside rows of cans were rotated with the outside rows once a week to aid in reducing

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* The term "pounds per acre" is used throughout this paper to indicate "pounds per 2 million pounds of soil."

Table I. Soil type, great soil group, parent material, drainage, location by county, and cultural status of 20 soils used in greenhouse study.

Soil No.	Soil* Type	County	Cropped or Uncropped	Great Soil Group (Provisional Classification)	Parent Material	Drainage
1	Amity sicl	Benton	U.C.	Grey-brown podzolic over a fragipan	Old Alluvium	Imperfect
2	Amity sil	Benton	C.	" " " " " "	" "	"
3	Amity sicl (1)	Washington	C.	" " " " " "	" "	"
17	Willamette sil	Benton	U.C.	" " " " " "	" "	Good
18	Willamette sil	Benton	C.	" " " " " "	" "	"
19	Willamette sil(2)	Washington	C.	Grey-brown podzolic or prairie-like	" "	"
11	Olympic cl (3)	Benton	C.	Prairie-like	Basalt residuum	"
12	Olympic sil (4)	Columbia	C.	Reddish-brown latosol	Loess-Volcanic ash	"
4	Cascade sil	Columbia	U.C.	Reddish-brown latosol or brown podzolic over a fragipan	" "	"
5	Cascade sil	Columbia	U.C.	" " " "	" "	"
6	Cascade l	Columbia	C.	" " " "	" "	"
7	Cascade l	Columbia	C.	" " " "	" "	"
13	Powell sil	Multnomah	U.C.	" " " "	" "	"
14	Powell sil	Multnomah	U.C.	" " " "	" "	"
15	Powell l	Columbia	C.	" " " "	" "	"
16	Powell sil	Multnomah	C.	" " " "	" "	"
8	Dayton sil	Linn	U.C.	Planosol	Old Alluvium	Poor
9	Dayton sic (5)	Linn	U.C.	" "	" "	"
10	Dayton sicl	Benton	C.	" "	" "	"
20	Viola sil	Columbia	U.C.	" "	Loess-Volcanic ash	"

* The soil type given conforms with the classification used when these areas were mapped, from 1922 to 1929. Current correlation studied in the area have not progressed far enough to reclassify all of the sites. However, certain changes are indicated in the footnotes.

(1) Mapped Amity but differs from Amity in Benton County.
(2) Mapped Willamette but differs from Willamette in Benton County.
(3) Mapped Olympic but similar to Dixonville.
(4) Mapped Olympic but similar to Cascade.
(5) This soil was taken from the B_2 horizon (13-24 inches).

Table II. Some chemical properties of 20 soils used in the greenhouse study.

Soil No.	pH	Exchangeable Cations - m. e./100g. K	Ca	Mg	H	C. E. C. m. e./100g.	% Base saturation with K before cropping	Available P PP2M
1	5.1	1.2	8.3	4.6	7.4	22.0	5.6	102
2	5.3	0.6	10.0	3.1	5.0	19.6	3.2	48
3	5.3	0.2	7.5	2.3	5.2	16.4	1.3	31
17	6.2	0.9	11.9	2.9	3.1	21.2	4.3	132
18	5.7	0.9	13.9	6.7	4.2	26.8	3.3	40
19	5.3	0.1	7.0	2.1	5.5	15.1	0.9	21
11	5.4	0.7	11.0	14.8	7.3	33.1	2.2	8
12	5.6	0.3	4.4	2.5	6.1	15.0	2.1	18
4	5.8	0.7	6.8	1.9	6.9	17.9	4.1	88
5	6.2	0.8	7.0	2.1	5.8	17.7	4.6	84
6	5.3	0.1	2.1	0.9	7.5	13.6	0.8	20
7	5.6	0.5	5.9	1.9	6.1	17.0	3.2	34
13	5.9	1.1	11.5	4.6	8.1	27.0	3.9	108
14	5.3	0.4	8.3	2.5	10.7	23.8	1.9	45
15	5.4	0.1	4.5	0.9	7.8	17.3	0.8	54
16	6.0	0.5	7.4	0.9	5.3	16.2	2.8	88
8	5.3	0.2	7.5	3.8	2.8	14.4	1.1	13
9	5.6	0.4	20.5	14.2	2.1	34.3	1.1	18
10	5.0	0.2	5.1	3.1	5.5	15.3	1.4	17
20	5.0	0.1	2.2	1.2	6.2	11.2	1.2	12

light and temperature variations.

The moisture retained at 0.1 atmosphere tension was determined on each soil and the moisture content of the soils adjusted to 85 per cent of the value by additions of distilled water. Enough quartz sand was added to the surface of the soils in the cans to a uniform total weight of nine pounds. The moisture content of the soils was periodically restored by additions of distilled water to bring the weight up to nine pounds. Cans without drains were employed to prevent leaching of nutrients. A glass tube was inserted into each can, at the time they were filled with soil, to check against overwatering.

Ladino clover was seeded March 2, 1954. When the seedlings were putting out their second trifoliate leaves, they were thinned to six plants per can. The first cutting was made May 18 when the clover was in half bloom. Subsequent cuttings were made at three to six-week intervals depending upon the rate of growth. The tenth and final harvest was made on January 14, 1955. After the final harvest the roots were removed from the soil and soil samples were taken. As the crops and roots were harvested they were oven-dried at 70° C., weighed, ground in a Wiley mill, and analyzed for potassium. The plant material from two replications (ie. reps 1 and 2, 3 and 4, 5 and 6) were composited before yield weights and potassium determinations were made. Notes were kept on the time of the appearance of potassium deficiency symptoms in the clover in order to ascertain at what level of potassium in the plant material this deficiency symptom occurred.

Laboratory procedures

Plant analyses: All potassium determinations were made with a Beckman Model B flame photometer. Analyses of all plant material were made according to the method of Attoe and Truog (5, pp. 222-224) in which the ground plant material is shaken for one hour with 100 ml of 2.0 normal ammonium acetate--0.2 normal magnesium acetate, filtered into 100 ml volumetric flasks, made to volume, and the potassium content determined on the flame photometer.

Soil analyses: Exchangeable potassium was determined by shaking 10 grams of air-dry soil with 100 ml of neutral, normal ammonium acetate for one hour, leaching with an additional 150 ml of ammonium acetate on a Buchner funnel, making to a total volume of 250 ml. and determining potassium in the flame photometer.

The extraction with nitric acid was made according to the procedure of Pratt and Morse (38, pp. 1-4) in which 2.5 grams of air-dry soil are placed in 100 ml beakers, 25 ml of normal nitric acid added, the beakers covered with watch glasses and placed in a constant temperature oil bath at 113° C. for 25 minutes. This extract was then filtered, washed with 0.1 normal nitric acid, made to a volume of 100 ml and a aliquot put in the flame photometer. Potassium released by the acid from nonexchangeable forms was calculated by subtracting the exchangeable potassium, determined previously, from the total potassium extracted by the nitric acid.

Exchangeable calcium and magnesium were determined with the flame photometer on the same extract used in determining exchangeable potassium. Exchangeable hydrogen was determined by shaking 10 grams of air-dry soil with neutral normal barium acetate for 1 hour, leaching with additional barium acetate on a Buchner funnel and titrating the leachate with 0.1 normal sodium hydroxide using phenolphthalein as an indicator.

Cation exchange capacity was determined according to the method of Schollenberger and Simon (47, pp. 14-17) with certain modifications. Tenth normal hydrochloric acid was used to displace the ammonia instead of sodium chloride and the distillate caught in a saturated boric acid solution and titrated with standard sulfuric acid.

Available phosphorus was determined according to the method outlined by Olsen et al (31, pp. 12-16) using sodium bicarbonate as the extracting solution and determining the phosphorus colorimetrically on a Cenco photolometer.

The pH's of the soil samples were determined with a glass electrode on a saturated paste that had been allowed to set for an hour with occasional stirring.

RESULTS

Greenhouse trial

A summary of the greenhouse cropping data is presented in Tables III and IV. Table III gives the values in PP2M or (pounds per 2 million pounds of soil), for exchangeable potassium before and after cropping, change in exchangeable potassium during cropping, total amount of potassium removed by cropping, potassium released from non-exchangeable forms during cropping, and the per cent of the total potassium removed by cropping coming from exchangeable and moderately available forms. The amount of potassium released from nonexchangeable forms during cropping was obtained by subtracting the decrease in exchangeable potassium during cropping from the total amount of potassium removed by cropping. Tables XIII, XIV, and XV in the appendix list the yield of clover at each harvest, per cent potassium in clover at each harvest, and cumulative uptake of potassium by the clover.

The soils contained an average of 398 pounds of exchangeable potassium per acre, ranging from 88 to 950 pounds. During cropping the exchangeable potassium level decreased an average of 239 pounds per acre, for an average reduction of 60 per cent. The clover removed an average of 556 pounds of potassium per acre, varying from 80 to 1400 pounds; of this, from 14 per cent to 100 per cent, or an average of 56 per cent, was released from nonexchangeable forms. The difference in the amount of potassium removed from the soils by

Table III. Change in exchangeable K during growth of ten cuttings of clover in the greenhouse, the calculated release of K from nonexchangeable forms, and sources of K taken up by the clover.

Soil No.	Exchangeable K			Total K removed by cropping PP2M	K released from nonexchangeable forms during cropping PP2M	Source of K removed by cropping	
	Before cropping PP2M*	After cropping PP2M	Decrease during cropping PP2M			% from exchangeable forms	% from moderately available form
1	950	210	740	1371	631	54	46
2	488	194	294	1160	866	25	75
3	162	138	24	224	200	11	89
17	712	200	512	1400	888	37	63
18	688	234	454	1387	933	33	67
19	112	132	-20	249	269	0	100
11	562	205	357	1232	875	29	71
12	238	125	113	235	122	48	52
4	574	156	418	567	149	74	26
5	624	189	435	572	137	76	24
6	88	116	-28	80	108	0	100
7	424	141	283	466	183	61	39
13	824	193	631	732	101	86	14
14	350	128	222	305	83	73	27
15	112	122	-10	120	130	0	100
16	362	118	244	348	104	70	30
8	126	122	4	148	144	3	97
9	288	213	75	246	171	30	70
10	164	118	46	184	138	25	75
20	106	125	-19	88	107	0	100
Average	398	159	239	556	311	44	56

* Pounds per 2 million pounds of soil.

Table IV. Exchangeable K before and after cropping and K extracted by HNO_3 for 20 soils used in greenhouse study.

Soil No.	Exchangeable K: Before cropping PP2M	Exchangeable K: After cropping PP2M	K extracted by HNO_3: Total PP2M	K extracted by HNO_3: Moderately* available PP2M
1	950	210	2740	1790
2	488	194	2500	2012
3	162	138	960	789
17	712	200	2740	2028
18	688	234	2220	1532
19	112	132	1100	988
11	562	205	2160	1598
12	238	125	520	282
4	574	156	1044	470
5	624	189	1260	636
6	88	116	360	272
7	424	141	860	436
13	824	193	1420	596
14	350	128	700	350
15	112	122	480	368
16	362	118	780	418
8	126	122	608	482
9	288	213	1160	872
10	164	118	908	744
20	106	125	372	266
Average	398	159	1245	847

* K released from nonexchangeable forms by HNO_3

cropping was highly significant, the L.S.D. at the 0.01 level being only 44 pounds. Values for potassium released from nonexchangeable forms ranged from 83 to 933 pounds per acre.

Table IV shows the total amount of potassium extracted, and the amount of potassium released from nonexchangeable forms by boiling, normal nitric acid as compared to the exchangeable potassium before and after cropping. The nitric acid extracted over two and one half times as much potassium as was removed by ten successive cuttings of Ladino clover in the greenhouse.

Table V presents the linear correlation coefficients for the relationships between the total amount of potassium removed and the amount released from nonexchangeable forms by greenhouse cropping and the amount extracted, and the amount released by boiling, normal nitric acid, as well as exchangeable potassium before and after cropping.

The correlation coefficient for the amount of potassium released by nitric acid and that released by cropping was 0.937 which is highly significant. This relationship is shown graphically in Figure 1. The relationship between potassium removed by cropping and potassium released by nitric acid $r = 0.934$, is shown in Figure 2. The correlation between the total potassium extracted by nitric acid and the total potassium removed by the clover was also highly significant (0.959) as indicated in Figure 3. The correlation coefficient between exchangeable potassium before cropping and the potassium removed by cropping was not as high but still highly significant (0.852) as shown in Figure 4. Figure 5 shows the very low

Table V. Linear correlation coefficients for the relationships between K extracted from 20 soils by cropping and K extracted by chemical methods.

	Exchangeable K before cropping	K released from nonexchangeable forms during cropping	K removed in 10 harvests	K removed in 6 harvests	K removed in 3 harvests	% base saturation with K before cropping
Exchangeable K before cropping		0.174	0.852		0.961	
Exchangeable K after cropping		0.725	0.835			
Decrease in exchangeable K during cropping						0.946
% K in clover from nonexchangeable forms	-0.672					
K released to HNO_3 from nonexchangeable forms	0.586	0.937	0.834			
Total K in HNO_3 extract			0.959	0.936		

For 18 d.f. r = 0.444 at the 5% level
For 18 d.f. r = 0.561 at the 1% level

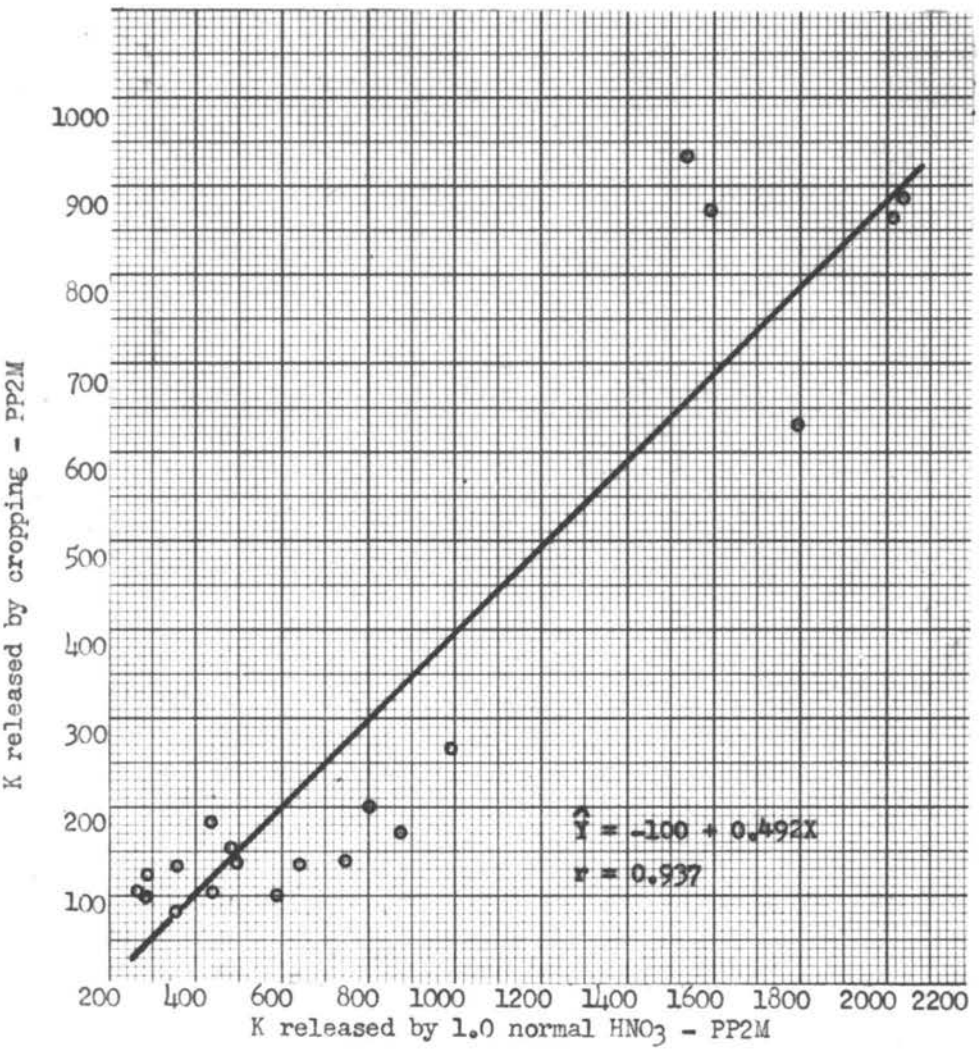


Figure 1. Relationship between the K released from twenty soils by ten successive cuttings of clover in the greenhouse and the K released by 1.0 normal HNO_3

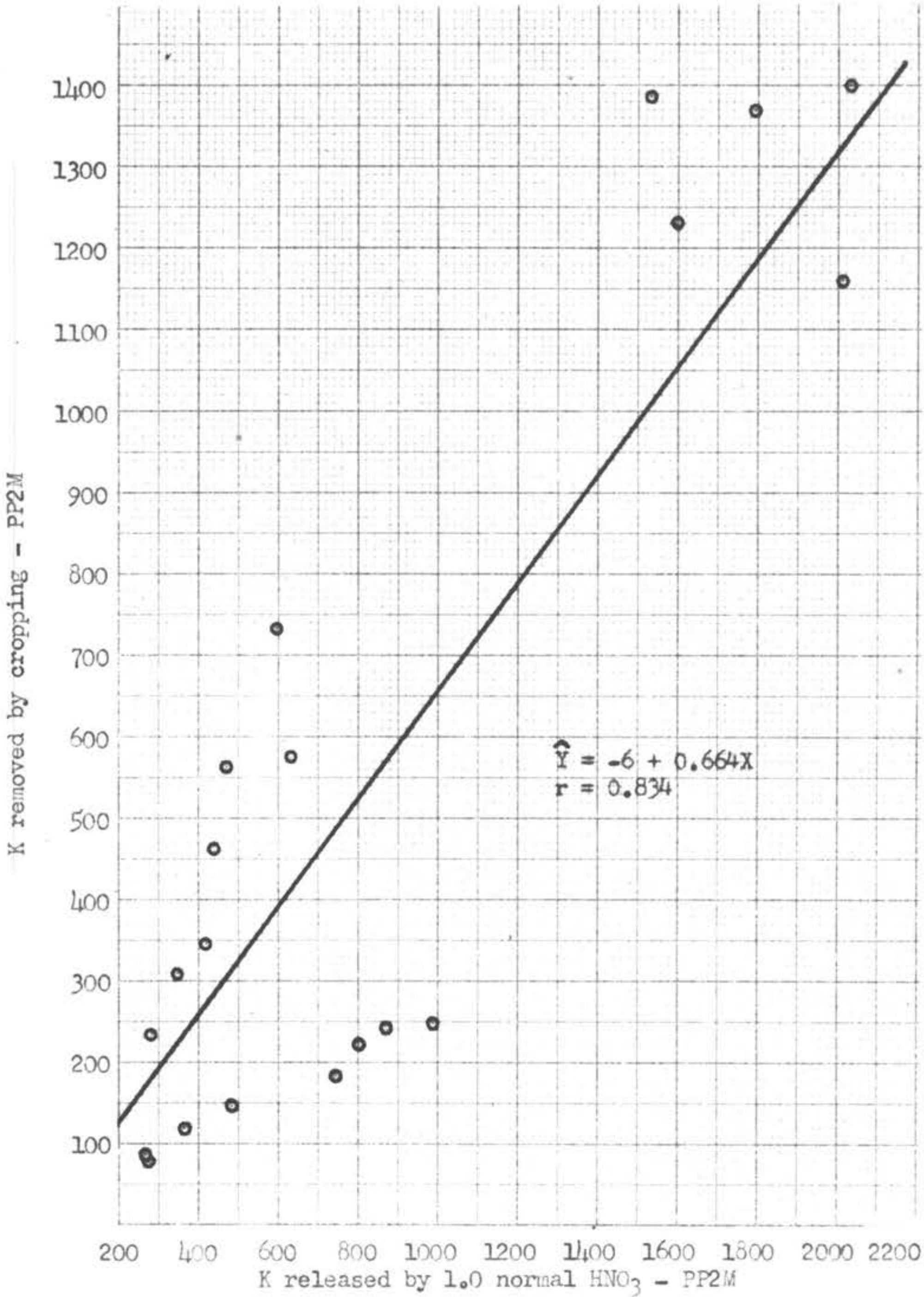


Figure 2. Relationship between the K removed from twenty soils by ten successive cuttings of clover in the greenhouse and the K released by 1.0 normal HNO_3

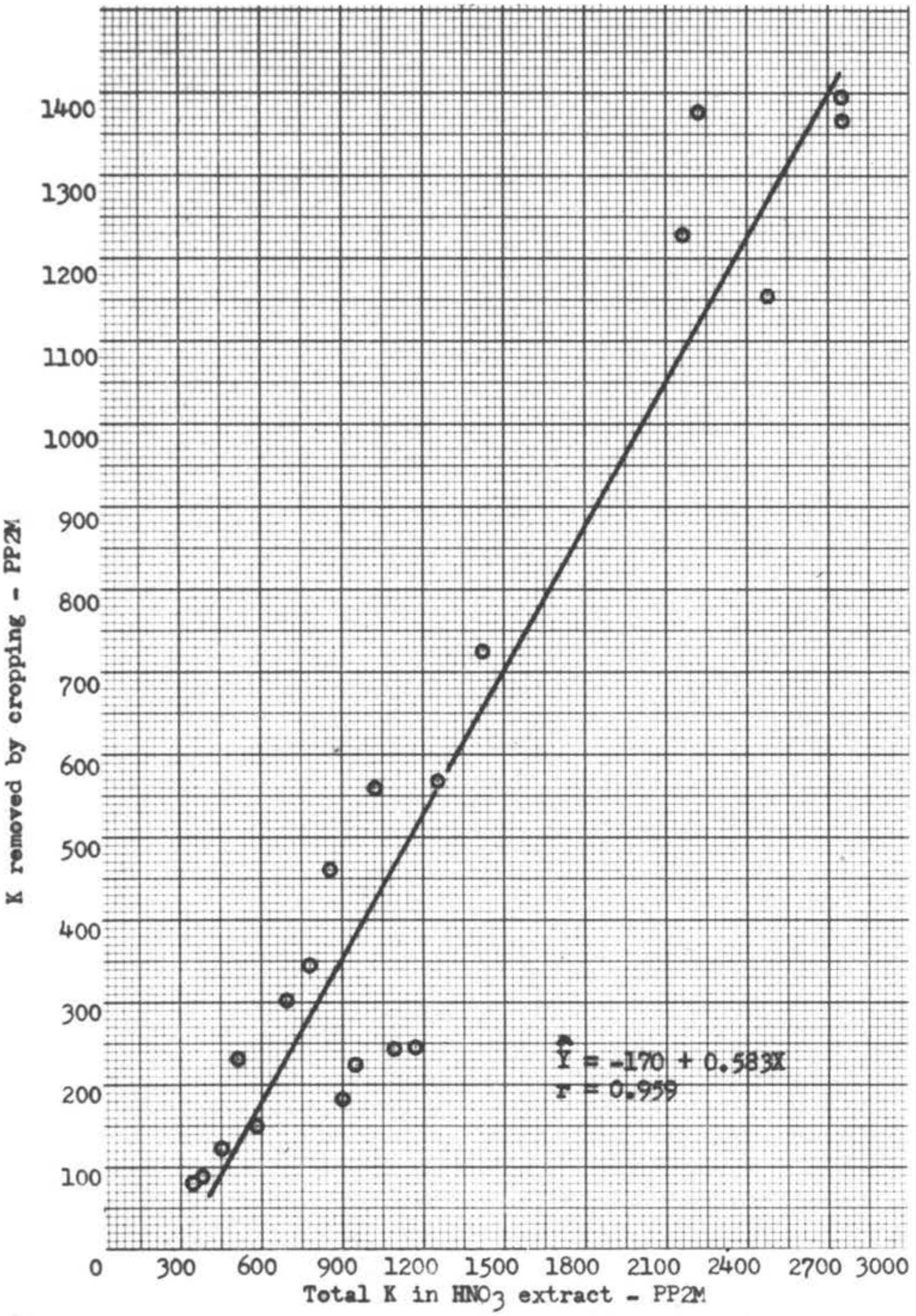


Figure 3. Relationship between the K removed from twenty soils by ten successive cuttings of clover in the greenhouse and the total K extracted by boiling 1.0 normal HNO_3

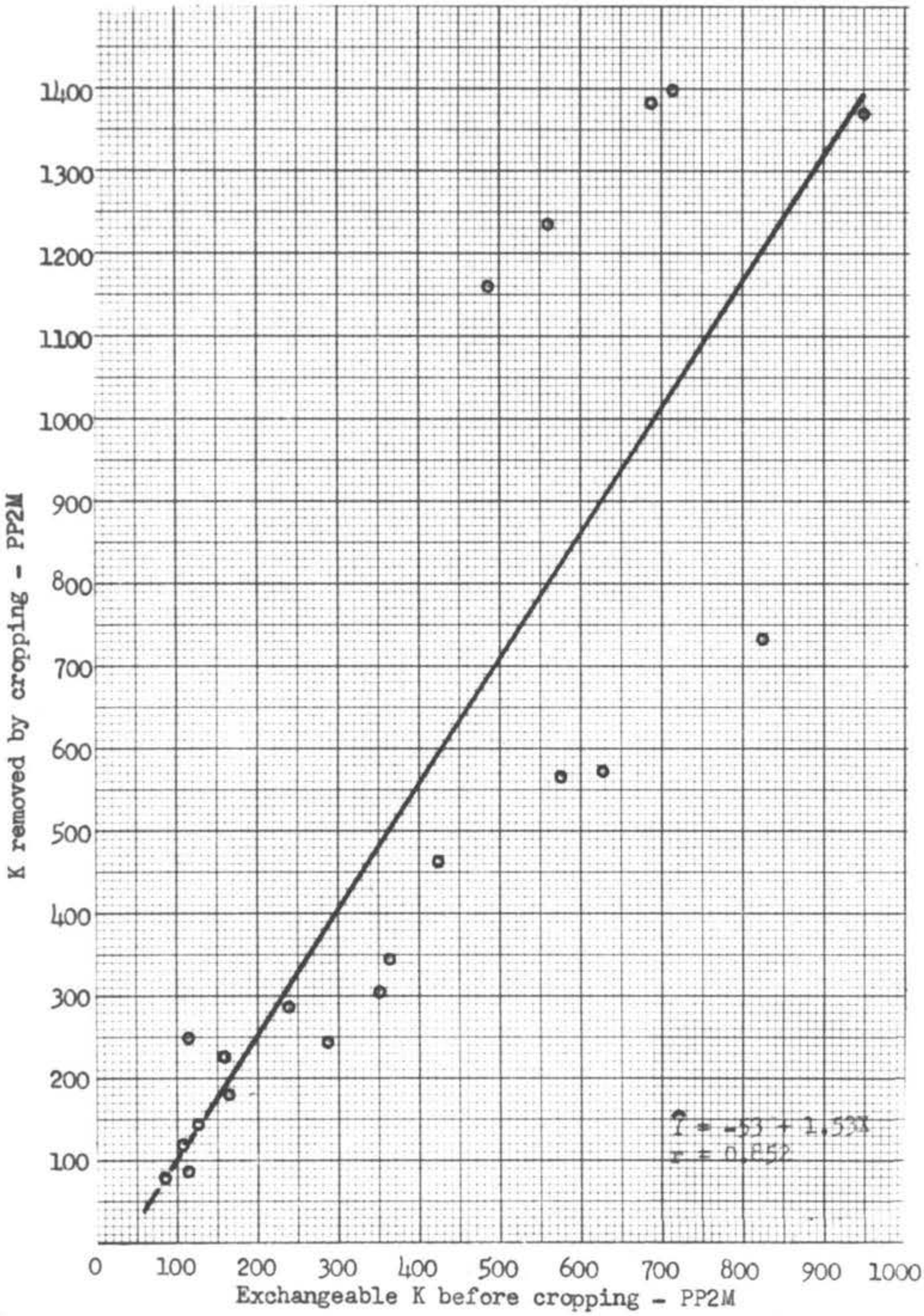


Figure 4. Relationship between the K removed from twenty soils by ten successive cuttings of clover in the greenhouse and the exchangeable K before cropping

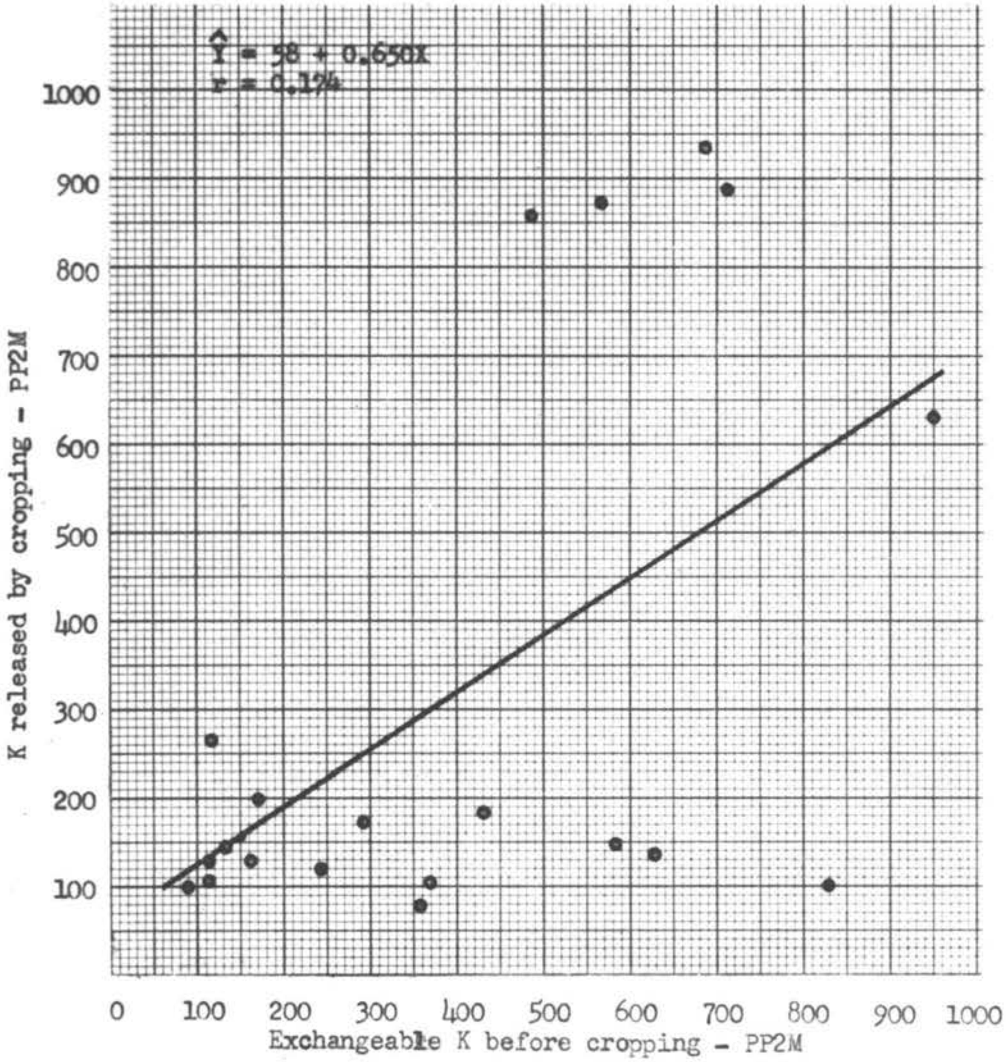


Figure 5. Relationship between the K released by twenty soils to ten successive cuttings of clover in the greenhouse and the exchangeable K before cropping

correlation between exchangeable potassium before cropping and potassium release from nonexchangeable forms during cropping. This correlation coefficient was only 0.174 which was not significant. The correlation coefficient for exchangeable potassium after cropping and the potassium release from nonexchangeable forms during cropping was much higher (0.725). The range in exchangeable potassium after cropping was much narrower than in exchangeable potassium before cropping, 116-234 pounds per acre as compared to 88-950 pounds per acre.

The potassium removed in six harvests of clover was almost as highly correlated with the total potassium in the nitric acid extract as was the amount of potassium removed in ten cuttings. The correlation coefficient for six cuttings was 0.936, Figure 6, while that for ten cuttings was 0.959, Figure 3. The amount of potassium removed by three cuttings of clover was highly correlated with the exchangeable potassium before cropping (0.961) as shown in Figure 6. Figure 8 shows that the decrease in exchangeable potassium during cropping was significantly correlated with the per cent base saturation with potassium before cropping (0.946). The per cent of potassium removed by the clover coming from nonexchangeable forms was inversely related to the exchangeable potassium before cropping. The correlation coefficient for this relationship was -0.672, Figure 9. Exchangeable potassium before cropping and potassium released by nitric acid were not highly correlated r = 0.586, Figure 10.

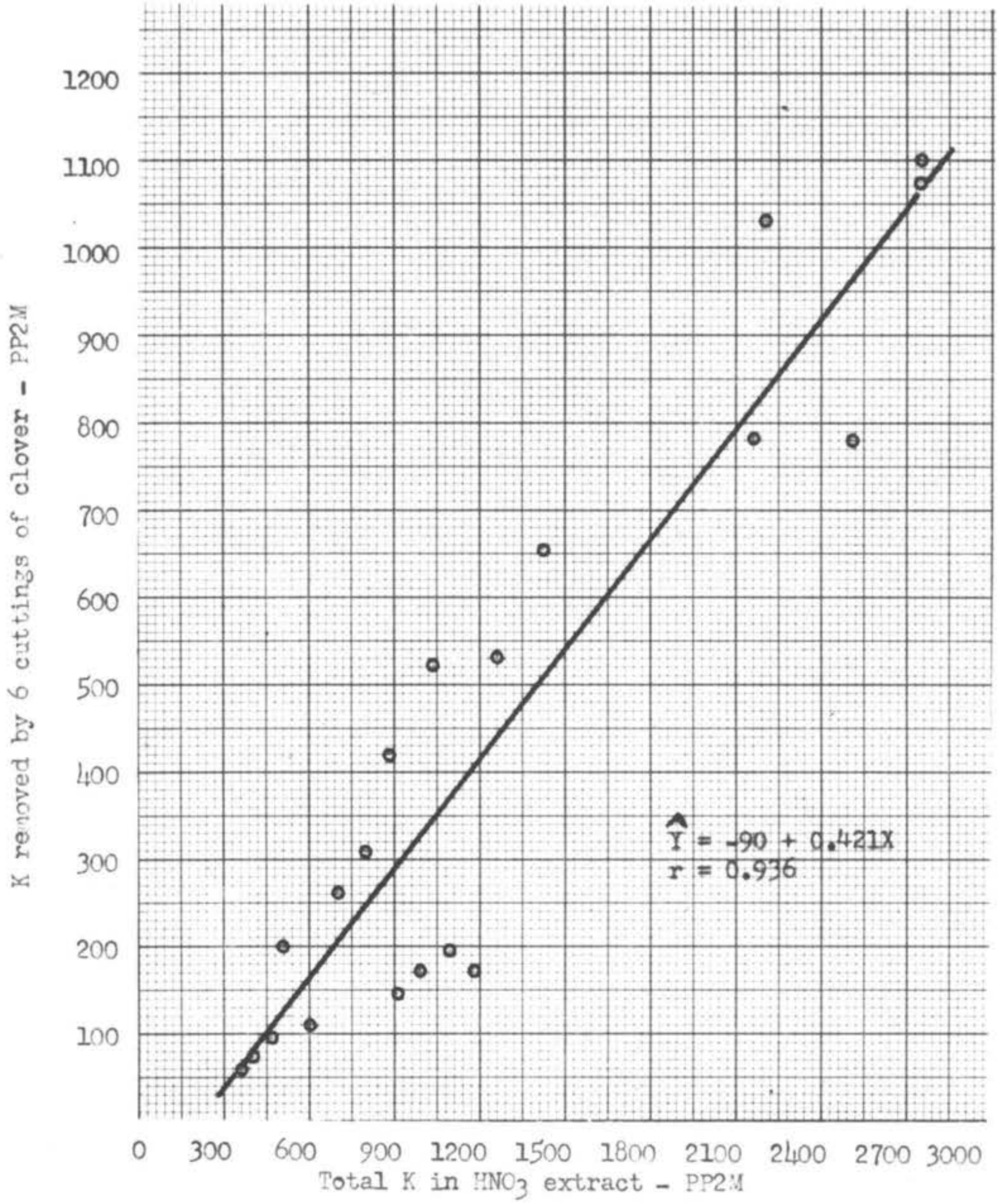


Figure 6. Relationship between the K removed by six successive cuttings from twenty soils in the greenhouse and the total K extracted by boiling, 1.0 normal HNO_3

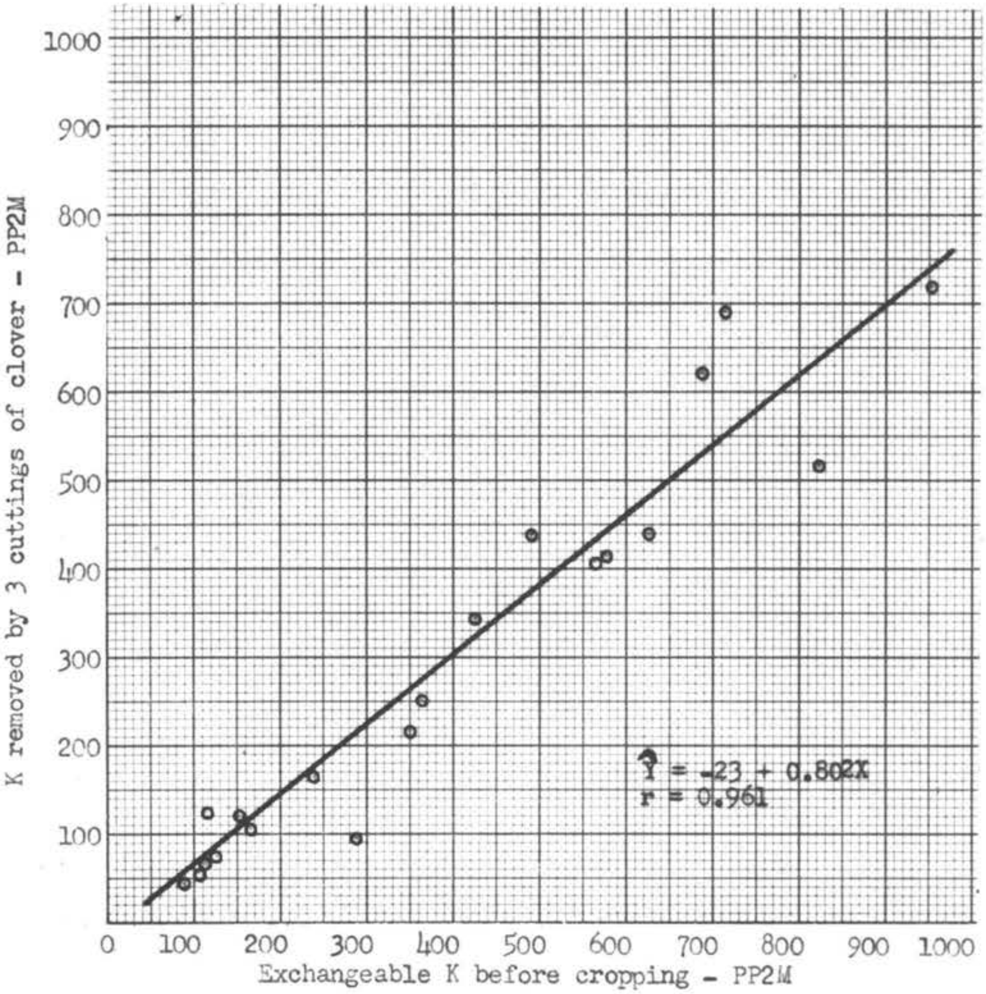


Figure 7. Relationship between the K removed from twenty soils by three successive cuttings of clover in the greenhouse and the exchangeable K before cropping

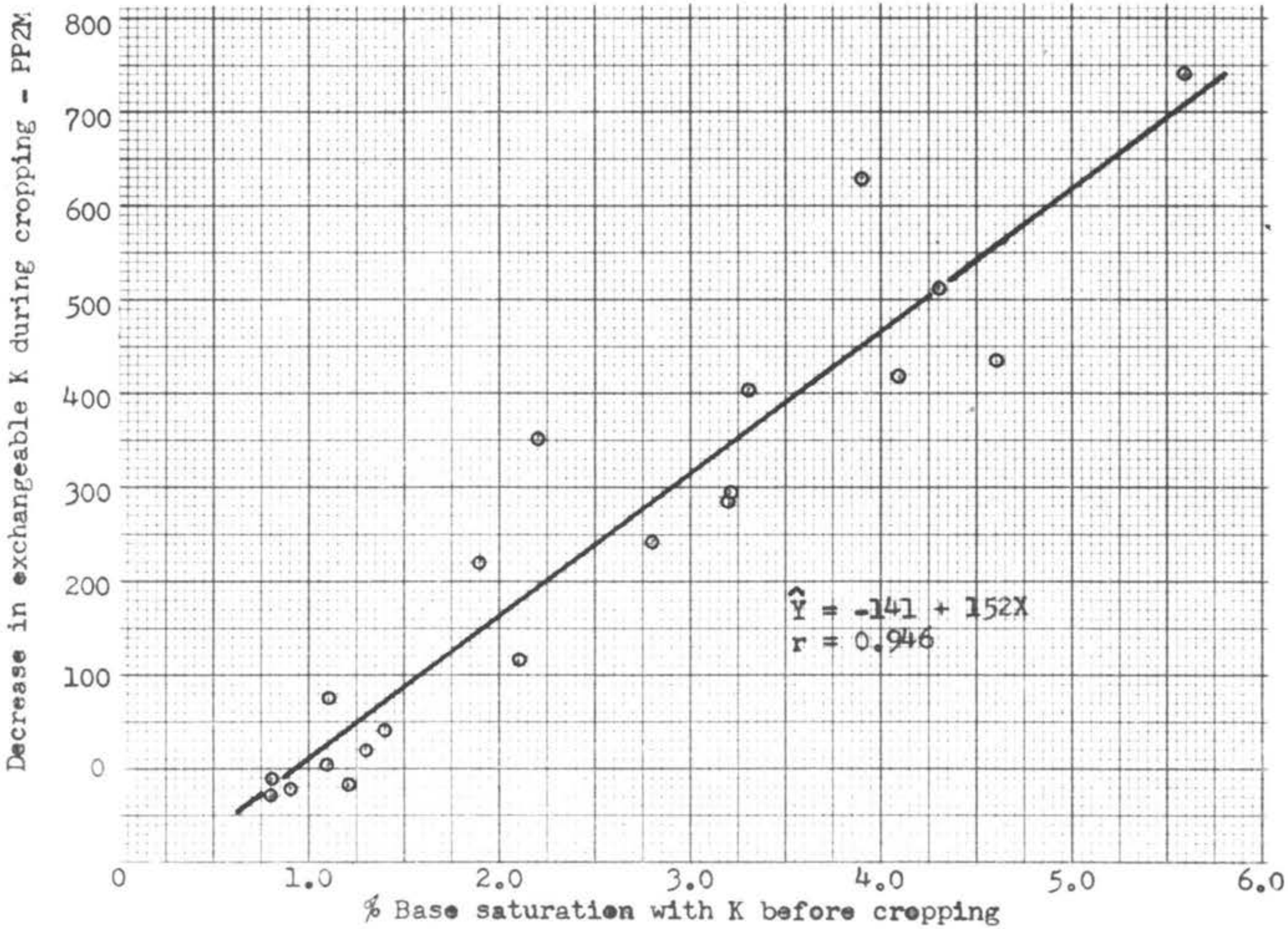


Figure 8. Relationship between the decrease in exchangeable K during cropping and the percent base saturation with K before cropping

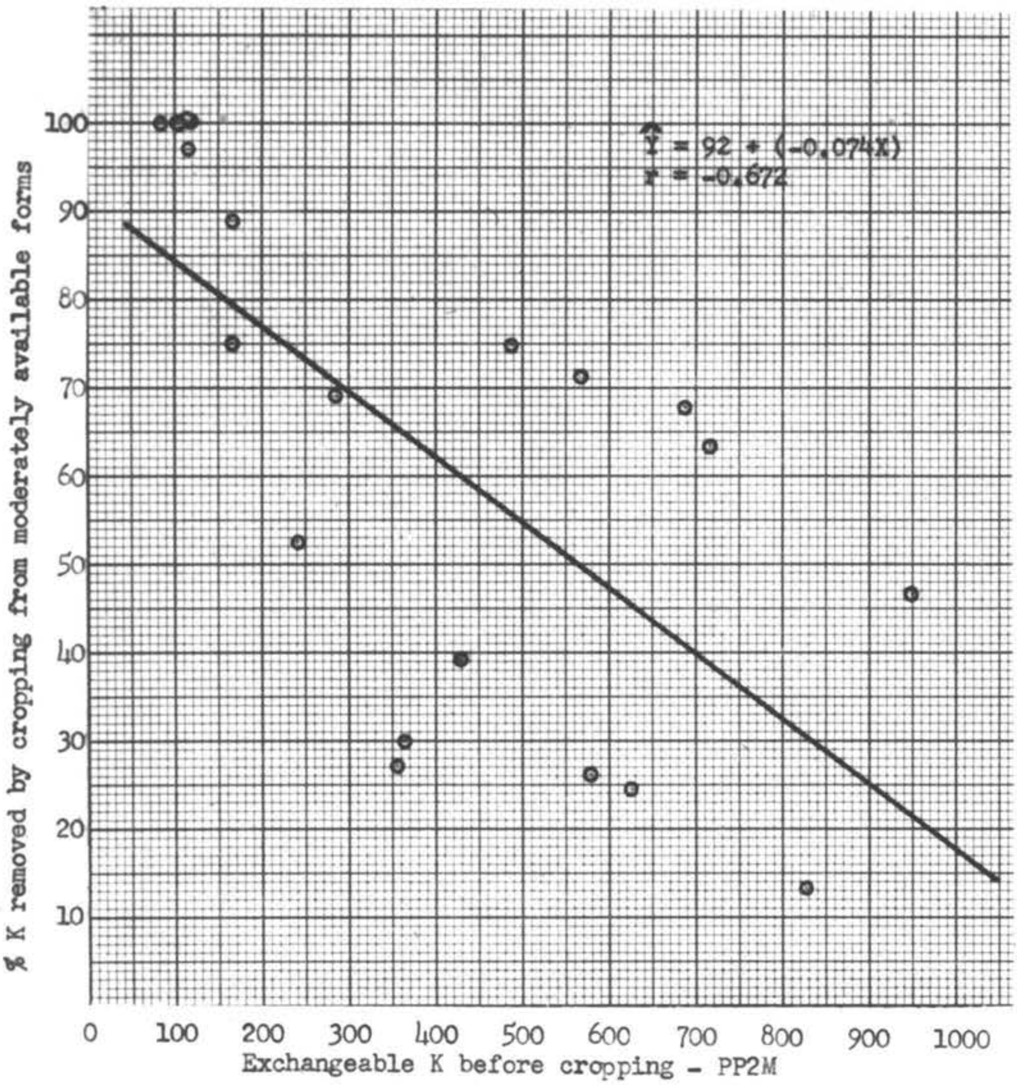


Figure 9. Relationship between the percent of K removed by cropping coming from moderately available forms and the **exchangeable** K before cropping

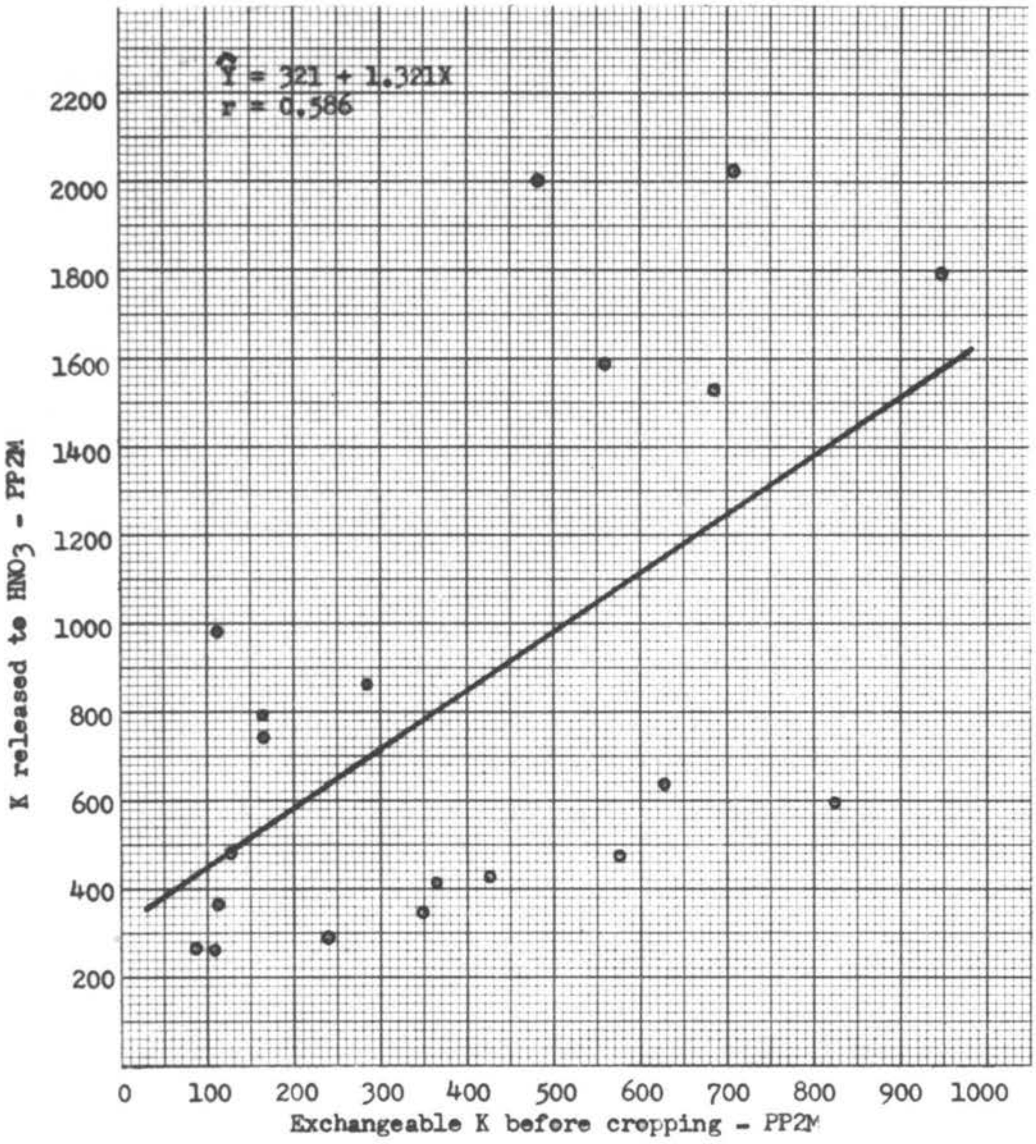


Figure 10. Relationship between the K released from twenty soils by boiling, normal HNO_3 and the exchangeable K before cropping

Randomly selected soil samples

Tables VI, VII, and VIII list the values for exchangeable potassium, potassium released from nonexchangeable forms by nitric acid, and total potassium in the nitric acid extract for the 0-6, 6-12, and 12-18 inch depths. Figure 11 and 12 illustrate these values graphically. Each value listed represents an average for ten sites. The data are grouped into soil series by county. The standard error of each mean is presented so that some indication of the variation in each soil series is possible as well as a comparison of the variability in exchangeable potassium and potassium release by nitric acid.

In order to compare exchangeable potassium values among soil series, the levels set up by the Oregon State College Soil Testing Laboratory were used. These levels are: 0-150, 150-250, and greater than 250 pounds per acre which represent a low, medium and high exchangeable potassium content. Pratt (38, pp. 15-20) suggested that in order to compare values for potassium release from nonexchangeable forms by nitric acid that the following values: less than 300, 300-500, 500-700, 700-900, and greater than 900 pounds per acre be considered, very low, low, medium, high, and very high respectively. These categories should be used only as relative indications and not as absolute values.

Table IX lists the percentage of soils in the low, medium, and high categories as regards to exchangeable potassium and potassium released from nonexchangeable forms by nitric acid. In order to have the same number of categories for potassium release as for exchangeable

Table VI. Exchangeable K in soil samples from 100 randomly selected sites - each value represents an average for ten sites.

	Exchangeable K - PP2M					
	0-6"		6-12"		12-18"	
	Ave.	S.E.*	Ave.	S.E.	Ave.	S.E.
Columbia Co.						
Cascade	224	30	184	13	176	19
Olympic	387	31	338	33	321	27
Powell	371	64	302	40	218	23
Multnomah Co.						
Powell	361	50	298	40	202	23
Washington Co.						
Amity	288	29	244	18	236	16
Willamette	304	37	280	16	226	14
Benton Co.						
Amity	302	28	364	28	306	21
Dayton	165	8	236	8	289	16
Olympic	359	52	368	52	337	52
Willamette	540	113	661	109	626	127
L.S.D. at .01	192		168		175	
Ave. S.E. in %		12.3		9.6		10.1

* S.E. = standard error of the mean.

Table VII. K released from nonexchangeable forms by HNO_3 in soil samples from 100 randomly selected sites - each value represents an average for ten sites.

	K released by HNO_3 - PP2M					
	0-6"		6-12"		12-18"	
	Ave.	S.E.*	Ave.	S.E.	Ave.	S.E.
Columbia Co.						
Cascade	379	36	308	21	304	19
Olympic	557	41	564	65	577	78
Powell	660	35	600	44	657	48
Multnomah Co.						
Powell	521	38	510	31	467	35
Washington Co.						
Amity	1300	104	1311	104	1491	117
Willamette	1040	48	1339	93	1325	78
Benton Co.						
Amity	1664	115	1544	132	1617	159
Dayton	915	79	731	83	743	70
Olympic	1092	198	904	205	729	131
Willamette	1889	113	1678	109	1615	155
L.S.D. at .01	353		382		374	
Ave. S.E. in %		8.1		8.7		9.4

* S.E. = standard error of the mean.

Table VIII. Total K in HNO_3 extract in soil samples from 100 randomly selected sites - each value represents an average for ten sites.

	Total K in HNO_3 extract - PP2M					
	0-6"		6-12"		12-18"	
	Ave.	S.E.*	Ave.	S.E.	Ave.	S.E.
Columbia Co.						
Cascade	603	38	492	18	480	12
Olympic	945	65	901	89	898	80
Powell	1031	81	901	64	875	56
Multnomah Co.						
Powell	882	79	808	67	669	51
Washington Co.						
Amity	1589	130	1555	120	1727	126
Willamette	1344	52	1619	96	1551	86
Benton Co.						
Amity	1966	124	1907	141	1924	159
Dayton	1080	80	967	83	1032	66
Olympic	1451	242	1272	244	1066	176
Willamette	2429	162	2339	153	2242	166
L.S.D. at .01	446		454		412	
Ave. S.E. in %		7.9		8.5		7.6

* S.E. = standard error of the mean.

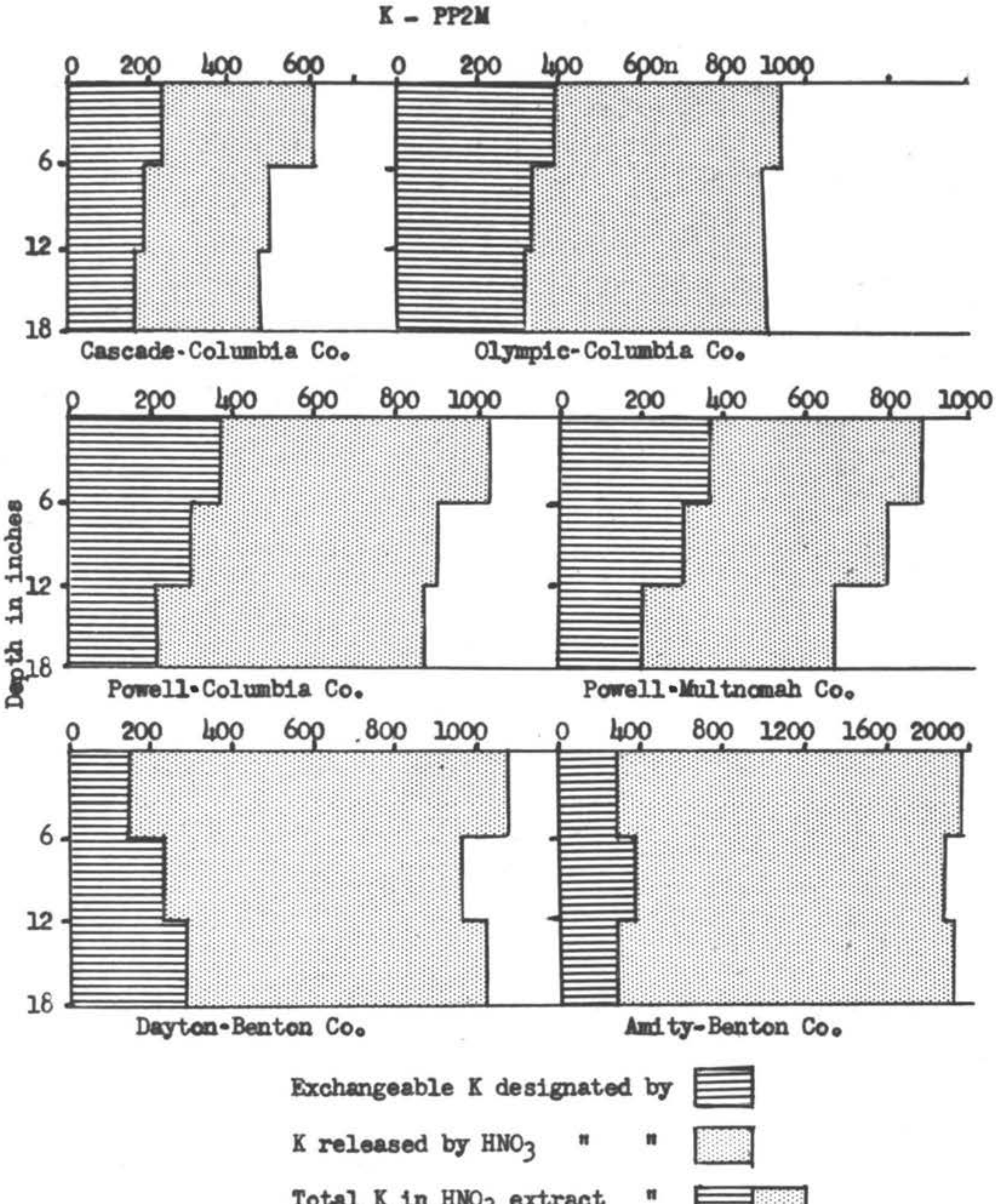


Figure 11 Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract with depth in soil samples from randomly selected sites in Western Oregon. (Each value is an average for ten sites)

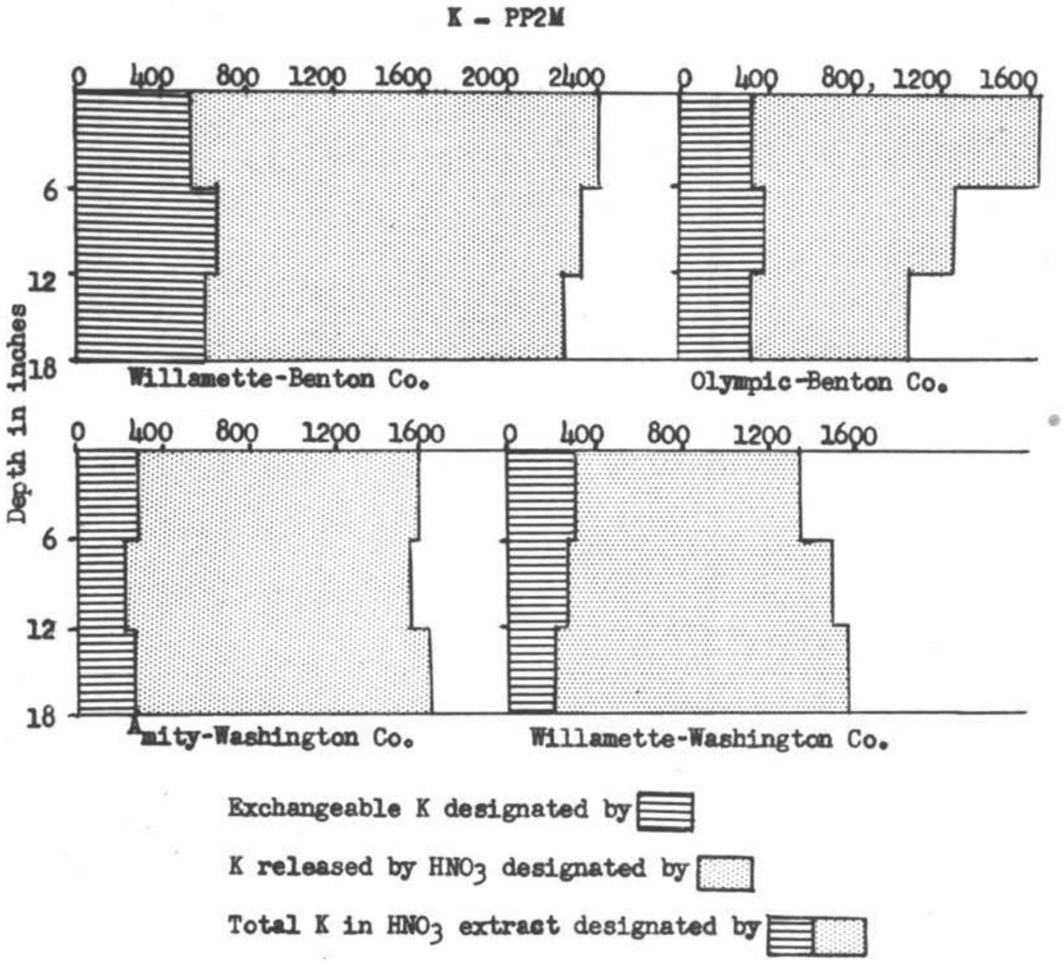


Figure 12. Distribution of exchangeable K, K released by HNO_3, and total K in HNO_3 extract with depth in soil samples from randomly selected sites in Western Oregon. (Each value is an average for ten sites)

Table IX. Percentage of soil samples from 100 randomly selected sites classified as low, medium, and high in exchangeable K and K released by HNO_3.

		Exchangeable K			K Release		
		Low	Med	High	Low	Med	High
Columbia Co.							
Cascade	0-6"	0	70	30	70	30	0
	6-12"	20	70	10	90	10	0
	12-18"	40	40	20	100	0	0
Olympic	0-6"	0	10	90	0	90	10
	6-12"	0	0	100	20	60	20
	12-18"	0	10	90	30	50	20
Powell	0-6"	0	20	80	0	90	10
	6-12"	0	40	60	0	100	0
	12-18"	10	60	30	0	80	20
Washington Co.							
Amity	0-6"	0	30	70	0	0	100
	6-12"	0	50	50	0	0	100
	12-18"	0	60	40	0	0	100
Willamette	0-6"	0	30	70	0	0	100
	6-12"	0	40	60	0	0	100
	12-18"	0	60	40	0	0	100
Multnomah Co.							
Powell	0-6"	0	20	80	0	100	0
	6-12"	20	20	60	10	90	0
	12-18"	20	40	40	40	60	0
Benton Co.							
Amity	0-6"	0	40	60	0	0	100
	6-12"	0	0	100	0	0	100
	12-18"	0	10	90	0	0	100
Dayton	0-6"	20	80	0	0	40	60
	6-12"	0	50	50	0	70	30
	12-18"	0	20	80	10	40	50
Olympic	0-6"	0	40	60	0	30	70
	6-12"	0	20	80	30	20	50
	12-18"	0	40	60	30	20	50
Willamette	0-6"	0	10	90	0	0	100
	6-12"	0	0	100	0	0	100
	12-18"	0	0	100	0	0	100

potassium 0-400, 400-800, and over 800 pounds per acre of K release were selected to represent low, medium and high levels.

Most of the Cascade soils were medium in exchangeable potassium and low in potassium release. Both exchangeable potassium and potassium released by nitric acid decreased with depth with the latter decreasing to a lesser degree. Exchangeable potassium ranged from 120 to 450 pounds per acre and potassium release from 186 to 650 pounds per acre.

The Olympic soils from Columbia County averaged high in exchangeable potassium and medium in potassium release. Decrease with depth was not as pronounced as in the Cascade soils. Exchangeable potassium ranged from 230 to 624 pounds per acre and potassium release from 268 to 1030 pounds per acre.

A high percentage of the Powell soils were high in exchangeable potassium and medium in potassium release. Exchangeable potassium dropped off rapidly with depth but potassium released by acid did not decrease nearly as much with depth. Exchangeable potassium ranged from 124 to 850 pounds per acre and potassium release from 350 to 876 pounds per acre.

The Amity soils in Washington County were medium to high in exchangeable potassium and all of the samples were high in potassium release. Exchangeable potassium decreased slightly with depth but potassium release increased slightly with depth. Exchangeable potassium ranged from 176 to 500 pounds per acre and potassium release from 880 to 2044 pounds per acre.

Most of the Willamette soils were high in exchangeable potassium with the remaining ones falling into the medium range. Potassium release was high in all samples. There was a decrease in exchangeable potassium with depth and potassium release increased with depth as in the Amity soils. Exchangeable potassium ranged from 176 to 600 pounds per acre and potassium release from 820 to 1756 pounds per acre.

Nearly all the Amity soils in Benton County were high in exchangeable potassium with only a few being in the medium range. Potassium release was high for all samples. Both exchangeable potassium and potassium release were quite uniform with depth. The range in exchangeable potassium was from 196 to 474 pounds per acre and that for potassium release from 860 to 2556 pounds per acre.

Nearly all of the Willamette soils in Benton County were high in exchangeable potassium and all were high in potassium release. Exchangeable potassium was uniform with depth with a slight decrease in potassium release with depth.

The Dayton soils were low to medium in exchangeable potassium in the surface 6 inches and medium to high in the other two depths. Potassium release was medium to high. Exchangeable potassium increased with depth while potassium release decreased slightly with depth. Exchangeable potassium ranged from 124 to 350 pounds per acre and potassium release from 388 to 1356 pounds per acre.

Not all of the soils previously mapped Olympic in Benton County are now considered to be Olympic. Consequently, the samples are more variable in both exchangeable potassium and also in potassium release than many of the other soils studied. Exchangeable potassium ranged from 196 to 232 pounds per acre and potassium release from 232 to 2590 pounds per acre. They were medium to high in exchangeable potassium and low to high in potassium release. Exchangeable potassium did not vary much with depth while potassium release decreased with depth.

There was a tendency for the potassium release values to be more characteristic of the soil series than the exchangeable potassium values. The standard errors of the means, expressed in percent, averaged 12.3, 9.6, and 10.1 for the exchangeable potassium values for the 0-6, 6-12, and 12-18 inch depths, respectively while those for potassium release were 8.1, 8.7, and 9.4 in the same order with depth. The standard errors for total potassium in the HNO_3 extract were still lower, being 7.9, 8.5, and 7.6 for the 0-6, 6-12, and 12-18 inch depths, respectively. This tendency was not consistent for all soil series.

Table X gives the linear correlation coefficients for some of the relationships involved in the data. When the samples from all 100 sites are considered, the correlation coefficients between exchangeable potassium and potassium release were low. For the 0-6, 6-12, and 12-18 inch depths the correlation coefficients were 0.30, 0.45, and 0.29 respectively. These values squared are 0.09, 0.20, and 0.08, which means that the variation in exchangeable potassium or potassium release were only associated from 8 to 20 percent with variations in the other. These data indicate the exchangeable potassium and potassium release appear to be s omewhat

Table X. Linear correlation coefficients for indicated relationships between soil samples from randomly selected sites

Relationship	Correlation Coefficient 0-6 inches	6-12 inches	12-18 inches
Exchangeable K vs. K release			
All soils	0.30	0.45	0.29
Amity series--Washington Co.	0.86	0.86	0.58
Amity series--Benton Co.	0.22	0.22	-0.05
Cascade series--Columbia Co.	-0.34	-0.52	-0.80
Dayton series--Benton Co.	0.14	-0.03	-0.35
Olympic series--Columbia Co.	0.60	0.58	-0.11
Olympic series--Benton Co.	0.81	0.70	0.81
Powell series--Columbia Co.	0.27	0.20	0.17
Powell series--Multnomah Co.	0.65	0.64	0.47
Willamette series--Washington Co.	-0.25	0.09	0.52
Willamette series--Benton Co.	0.03	-0.01	-0.32
	0-6" vs 6-12"	6-12" vs 12-18"	0-6" vs 12-18"
Exchangeable K (All soils)	0.87	0.78	0.93
K - release (All soils)	0.94	0.90	0.95

For all soils (98 d.f.) r = 0.198 at the 5% level
" " " " " r = 0.258 at the 1% level

For individual soils (8 d.f.) r = 0.632 at the 5% level
" " " " " r = 0.765 at the 1% level

independent of each other. The relationship between exchangeable potassium and the potassium release for individual soils varied considerably, the correlation coefficients for the relationship ranging from -0.80 to +0.86. The Amity soils in Washington County were the only ones in which exchangeable potassium was significantly correlated with potassium release by nitric acid. In the 12-18 inch depth of the Cascade soils there was a significant negative correlation between these values.

The correlation coefficient for exchangeable potassium in the 0-6 and 6-12 inch depths was 0.87, while that for the 6-12 and 12-18 inch depths was 0.93. These values squared are 0.76 and 0.86 which means that a measurement of exchangeable potassium in the 0-6 inch depth accounted for 76 percent of the variations of exchangeable potassium in the 6-12 inch depth and that the measurement of exchangeable potassium in the 6-12 inch depth accounted for 86 percent of the variation of exchangeable potassium in the 12-18 inch depth.

The potassium release values for the three depths were highly correlated. The coefficient of correlation between the 0-6 and 6-12 inch depths was 0.94, that between the 6-12 and 12-18 inch depths 0.90, and that between the 0-6 and 12-18 inch depths 0.95 which indicates a high degree of accuracy in prediction of potassium release for the 6-12 and 12-18 inch depths from that of the 0-6 inch depth.

Profile samples

The values for exchangeable potassium, potassium release from nonexchangeable forms by nitric acid, and the total potassium in the nitric acid extract for 26 profile samples are shown in Table XI. Figures 13 through 17 illustrate the change in these values with depth.

In Powell profile No. S53-Ore-26-2, Figure 13, exchangeable potassium decreased with depth from 186 pounds per acre in the surface to 106 pounds per acre in the 45-60 inch depth. Potassium release decreased from 414 to 318 pounds per acre. There appeared to be a discontinuity between the B_{22} and B_3 horizons, according to the results of mineralogical studies reported by Alexander et. al.(3, p. 4) and potassium release dropped off considerably in the B_3 horizon (33"-45"). The presence of profile discontinuities was indicated by abrupt changes in exchange capacity and/or the distribution of the various minerals in adjacent horizons.

The values for exchangeable potassium and potassium release decreased with depth in Powell profile No. S53-Ore-26-3 ranging from 226 to 106 pounds per acre for exchangeable potassium and from 454 to 286 pounds per acre for potassium release by nitric acid.

The third Powell profile, No. S53-Ore-26-4 contained more exchangeable potassium and also more acid releaseable potassium than the other two Powell profiles, especially in the upper 15 inches. At this point both exchangeable potassium and potassium released by nitric acid dropped off considerably. An increase in potassium release by nitric acid occurred in the B_2 horizon (23"-35") which was apparently another profile discontinuity.

The exchangeable potassium and potassium release by acid also

Table XI. Exchangeable K, K released from nonexchangeable forms by HNO_3 and total K in HNO_3 extract in profile samples (K expressed in PP2M)

	Exchangeable K	K released by HNO_3	Total K in HNO_3 extract
S53-Ore-26-1			
(Amity) 0-4	186	350	536
4-11	162	358	520
11-16	98	342	440
16-19	84	294	378
19-29	150	306	456
29-38	178	390	568
38-48	122	462	584
48-68	106	606	712
68-88	106	446	552
S53-Ore-26-2			
(Powell) 0-5	186	414	600
5-12	170	382	552
12-20	154	398	552
20-33	126	442	568
33-45	106	414	520
45-60	106	318	424
S53-Ore-26-3			
(Powell) 0-4	226	454	680
4-11	138	462	600
11-20	138	414	552
20-29	114	406	530
29-36	96	390	486
36-50	106	382	488
50-70	106	286	392

	Exchangeable K	K released by HNO_3	Total K in HNO_3 extract
S53-Ore-26-4			
(Powell) 0-4	800	688	1488
4-15	540	556	1096
15-23	182	722	904
23-35	138	830	968
35-52	114	730	844
52 +	118	530	648
S53-Ore-5-1			
(Cascade) 0-2	1000	488	1488
2-8	324	452	776
8-16	178	406	584
16-27	142	426	568
27-48	114	374	488
48-61	114	294	408
61-75	130	294	424
S53-Ore-5-2			
(Viola) 0-4	170	330	500
4-10	106	318	424
10-19	94	314	408
19-26	98	278	376
26-39	150	226	376
39-49	134	194	328
49-59	130	198	328
59-71	110	154	264

Table XI Con't. Exchangeable K, K released from nonexchangeable forms by HNO_3 and total K in HNO_3 extract in profile samples. (K expressed in PP2M)

	Exchangeable K	K released by HNO_3	Total K in HNO_3 extract
S53-Ore-5-3			
(Viola) 0-3	146	294	440
3-9	86	274	360
9-23	102	354	456
23-35	130	326	456
35-45	130	290	420
45-61	110	250	360
61-81	98	262	360
S53-Ore-5-4			
(Cascade) 0-3	636	780	1416
3-12	412	684	1096
12-23	266	702	968
23-36	130	646	776
36-49	114	582	696
49-63	102	594	696
63-79	98	518	616
79-89	94	346	440
89-101	98	326	424

	Exchangeable K	K released by HNO_3	Total K in HNO_3 extract
Amity			
0-6	864	1776	2640
6-13	664	2000	2664
13-18	564	1980	2544
18-26	484	1932	2416
26-36	404	1524	1928
36-60	316	812	1128
Dayton			
0-2	384	944	1328
2-12	276	1052	1328
12-13	324	676	1000
13-30	344	624	968
30-38	296	656	952
38-60	284	524	808
60-90	284	988	1272
Willamette			
0-10	684	2196	2880
10-21	544	1976	2520
21-32	424	1816	2240
32-46	464	1248	1712
46-60	404	1348	1752

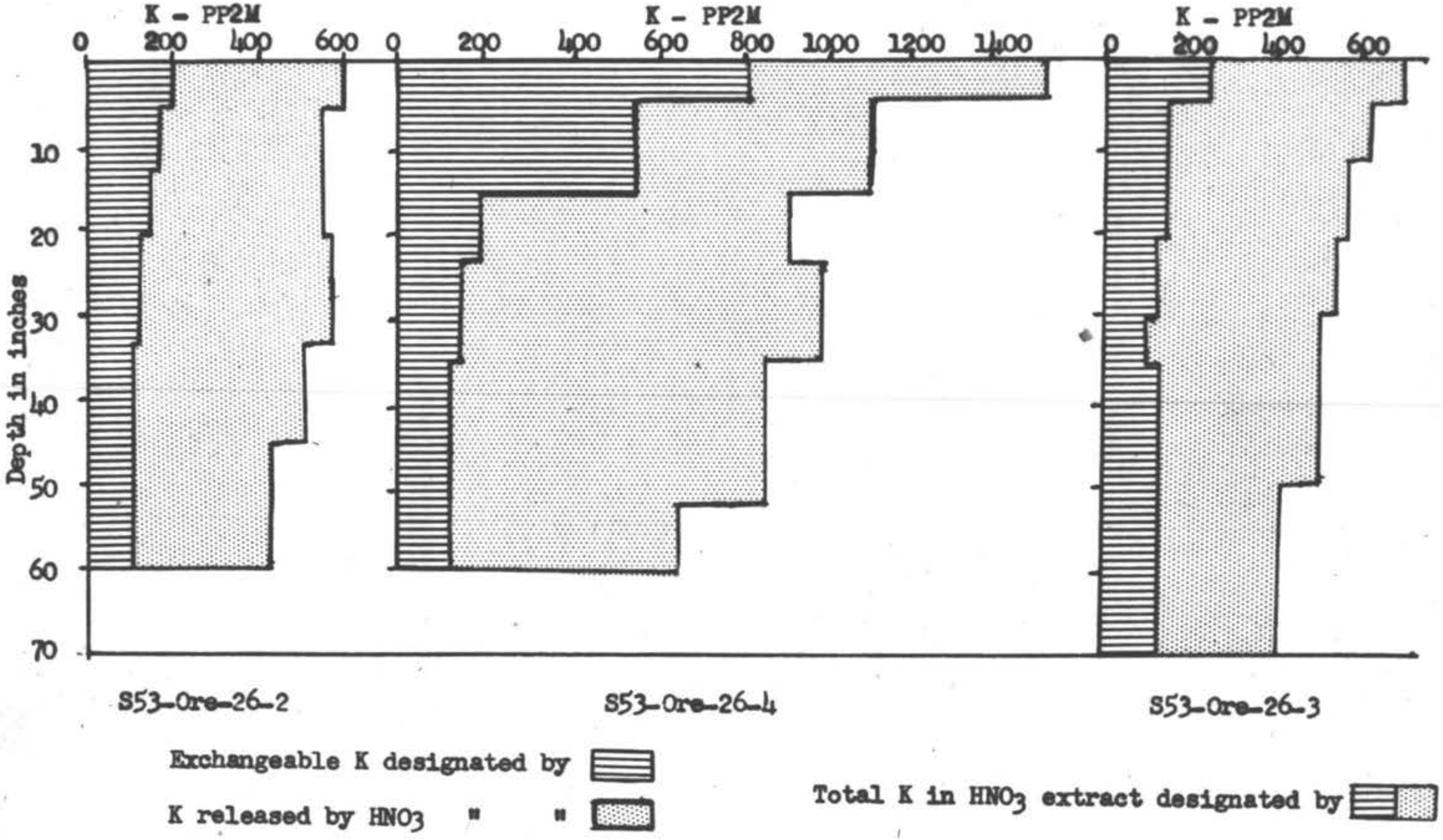


Figure 13. Distribution of exchangeable K, K released by HNO_3 and total K in HNO_3 extract in three Powell profiles

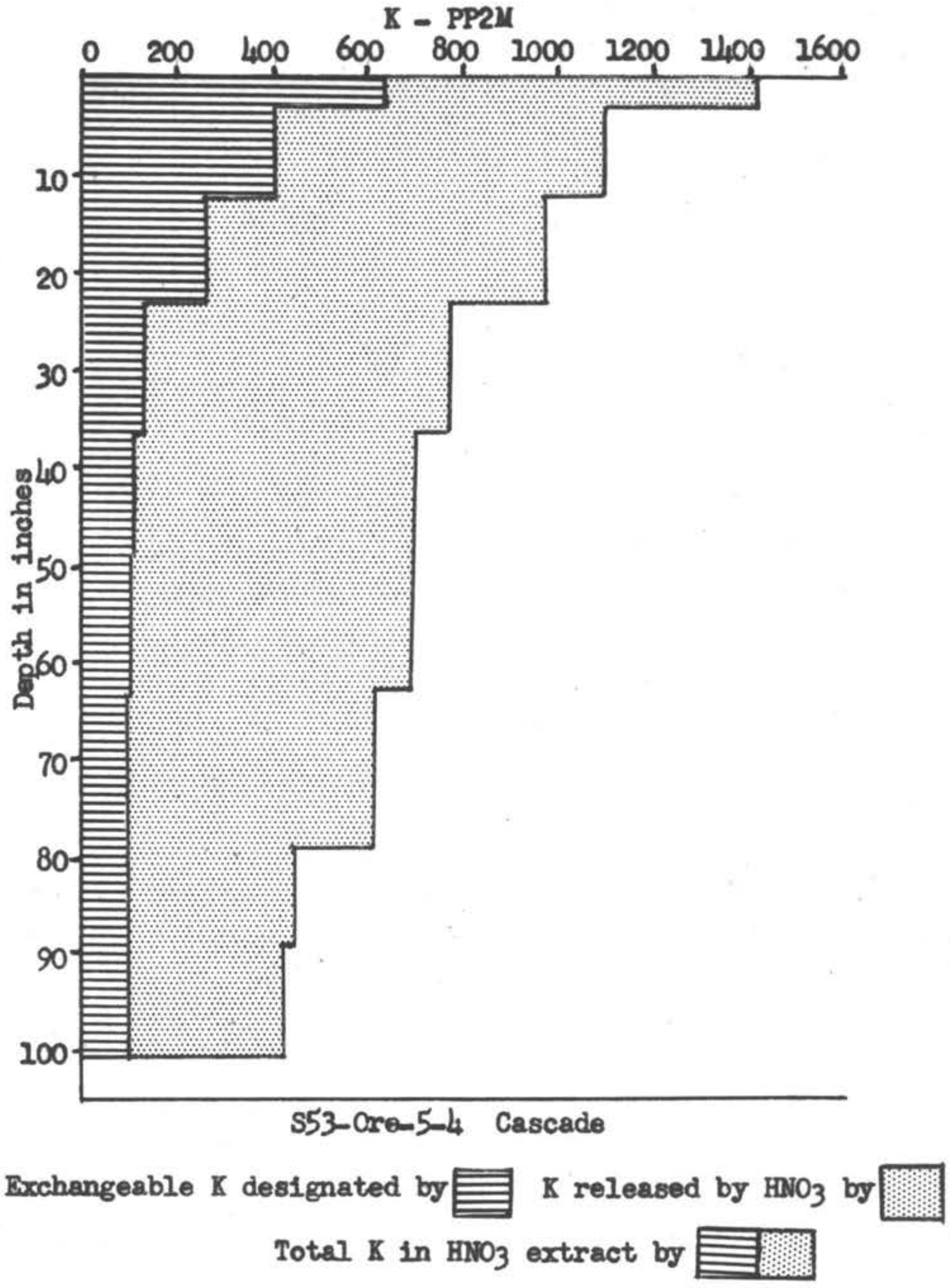


Figure 14. Distribution of exchangeable K, K released by HNO_3 and total K in HNO_3 extract in a Cascade profile

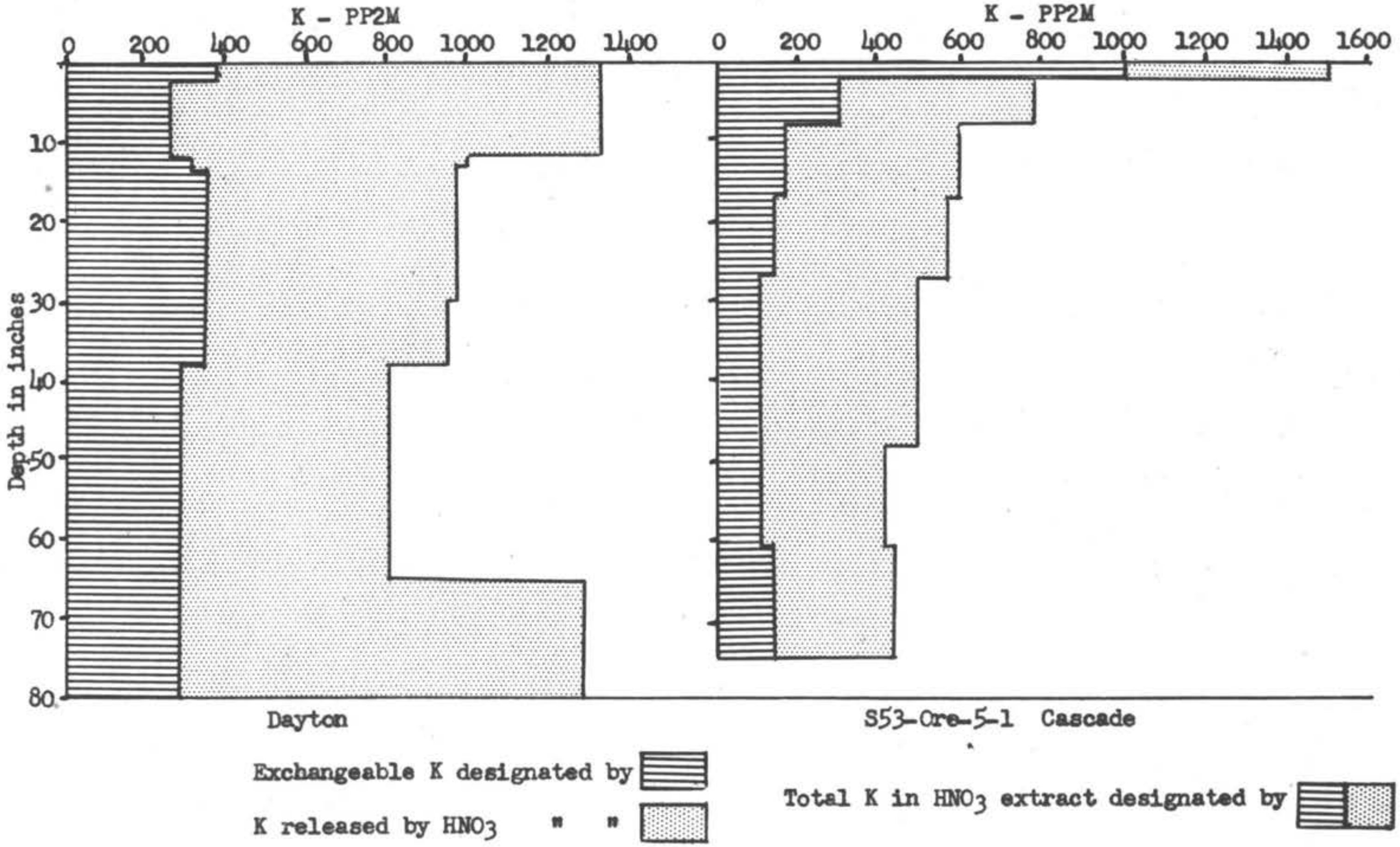


Figure 15. Distribution of exchangeable K, K released by HNO_3 and total K in HNO_3 extract in a Dayton and a Cascade profile

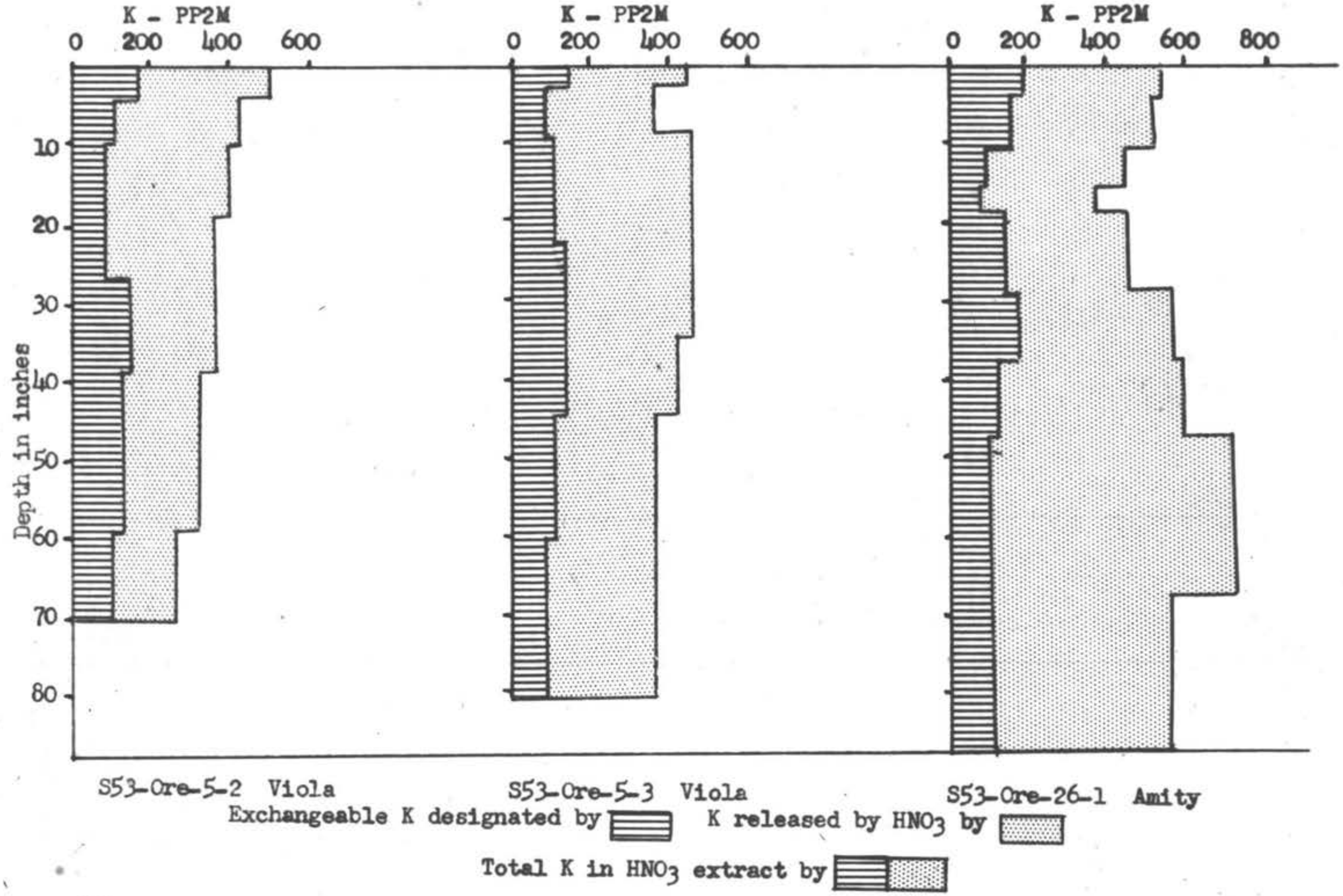
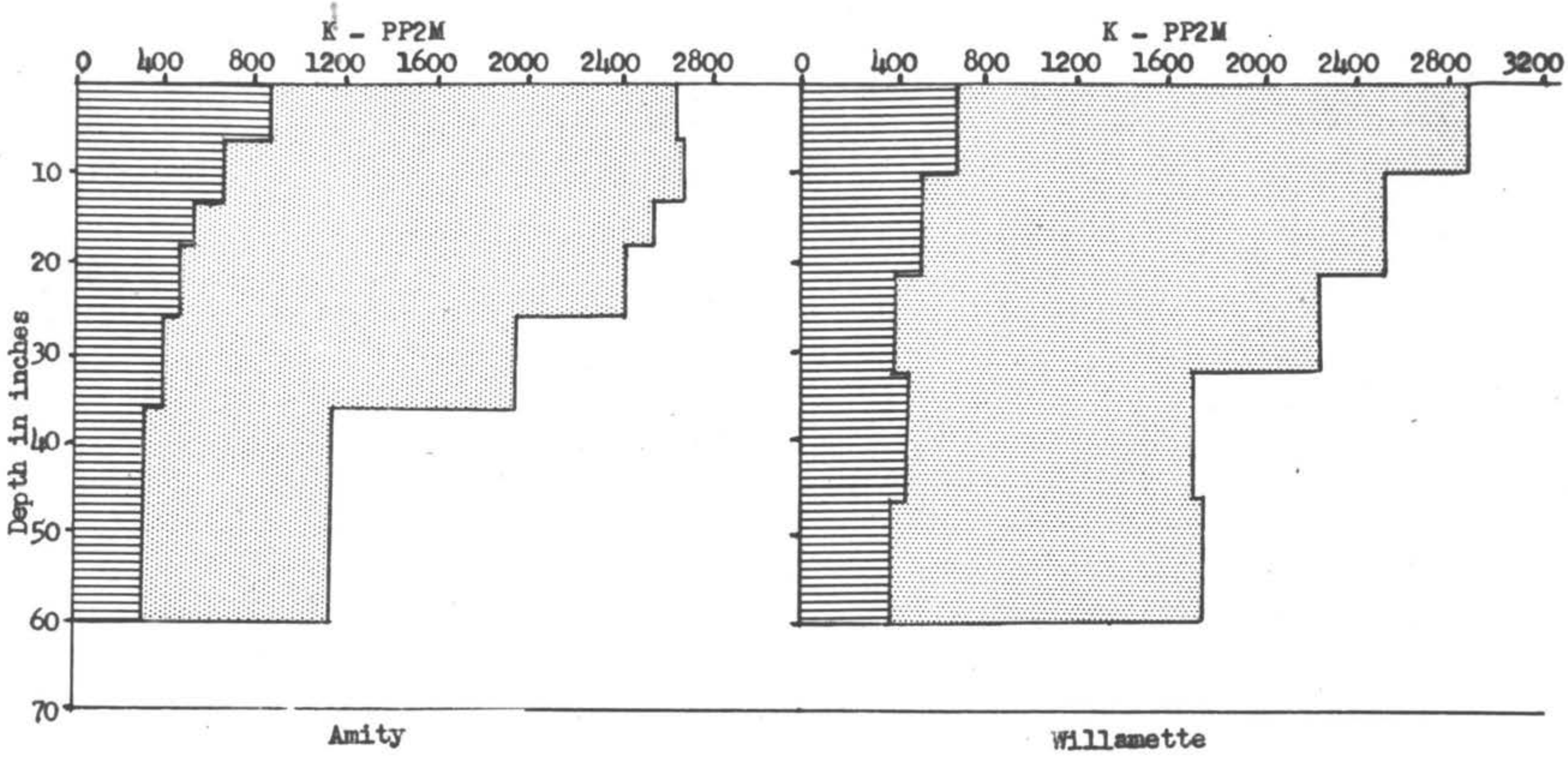


Figure 16. Distribution of exchangeable K, K released by HNO_3 and total K in HNO_3 extract in Viola and Amity profiles



Exchangeable K designated by

K released by HNO_3 " "

Total K in HNO_3 extract designated by

Figure 17. Distribution of exchangeable K, K released by HNO_3 and total K in HNO_3 extract in an Amity and a Willamette profile

decreased with depth in the Cascade profile No. S53-Ore-5-2, Figure 14, ranging from 636 to 98 pounds per acre for exchangeable potassium and 780 to 326 pounds per acre for potassium release. The mineralogical data indicated a discontinuity between the B_{11} and B_3 horizons but there was no sudden change in either exchangeable potassium or potassium release at this point.

In the Cascade profile No. S53-Ore-5-1, Figure 15, exchangeable potassium was very high in the surface two inches but decreased tremendously in the next horizon. Exchangeable potassium ranged from 1000 pounds per acre in the surface two inches to 130 pounds in the 61-75 inch depth. Potassium release decreased from 488 to 294 pounds per acre.

Profile No. S53-Ore-26-1, formerly mapped Amity, varied from 186 to 106 pounds of exchangeable potassium per acre with depth. The values for potassium release did not decrease with depth as in the other profiles but fluctuated in the different horizons. Both exchangeable potassium and potassium release decreased in the A_{21g} and A_{22g} horizons (11-16 and 16-19 inches) and increased in the next horizon again. There was a large increase in potassium release by acid in the C_{1g} horizon (48"-66").

In Viola profile No. S53-Ore-5-2 exchangeable potassium decreased in the A_{21g} and A_{22g} (10"-19" and 19"-26") horizons and increased again in the B_{2tg}. Potassium released decreased gradually with depth ranging from 330 to 150 pounds per acre. The mineralogical data indicated a discontinuity between the A_{22} and B_{2tg}

horizons.

The Viola profile No. S53-Ore-5-3 was very similar except that potassium release did not drop off as much with depth ranging from 294 to 262 pounds per acre.

Exchangeable potassium in the Dayton profile, Figure 15, decreased in the A_2 horizon (0-13"), increased again in the B_2 and was fairly consistent down to 80 inches. Potassium release by acid decreased in the B_2 and B_3 horizons (13"-38") and increased considerably again in the C_2 horizon (60"-80") indicating a difference in the underlying material at that depth.

Both exchangeable potassium and potassium release values in the Willamette and Amity profiles, Figure 17, were much higher than in the other profile samples. Exchangeable potassium ranged from 864 to 316 pounds per acre in the Amity profile and 684 to 404 pounds per acre in the Willamette profile. This decrease was quite gradual with depth with the Willamette being higher at the 60 inch depth. Potassium release values ranged from 1776 to 812 pounds per acre in the Amity profile and 2196 to 1348 pounds per acre in the Willamette. The greatest decrease in potassium release values occurred in the C horizon in both profiles, 36-60 inches in the Amity and 32-60 inches in the Willamette. Potassium release did not decrease as much with depth in the Willamette profile as in the Amity.

DISCUSSION

Greenhouse trial

In the greenhouse cropping trial, the clover on three of the soils (No. 6, 15, and 20, all derived from loess and volcanic ash) exhibited potassium deficiency symptoms by the second harvest. These three soils contained approximately 0.1 m.e. of exchangeable potassium per 100 grams of soil before cropping and released relatively low amounts of nonexchangeable potassium during cropping. The appearance of potassium deficiency symptoms was associated with a plant potassium content of 0.60 to 0.70 percent in the harvest following the appearance of the symptoms. By the time of the sixth harvest, the clover on all of the soils, with the exception of No. 1, 2, 11, 17, and 18, exhibited potassium deficiency symptoms. These five soils were all from one county. Four of them were derived from old alluvium and the other from basalt residuum. These soils were still producing vigorously growing clover without potassium deficiency symptoms at the end of the cropping period, 308 days, while the clover on many of the other soils was making very little growth and removing very little additional potassium.

Soils No. 1, 2, 11, 17, and 18 released greater amounts of potassium from nonexchangeable forms during cropping than the other soils. The amount of potassium removed by the clover in ten harvests from these soils was also significantly higher than from the other soils.

The soils derived from loess-volcanic ash (No. 4, 5, 6, 7, 12, 13, 14, 15, and 16) released less than 200 pounds of potassium per acre during the cropping period. The clover removed significantly less total potassium from these soils than from the other soils included in the study. Alexander et al (3, pp. 1-7) made mineralogical studies on the clay fraction of profile samples of the Cascade, Powell, and Viola series from sites in this same area and found them to be low in mica and relatively high in vermiculite and chlorite. Since both vermiculite and chlorite are formed from micas by replacement of potassium with other ions, these soils would tend to release relatively small amounts of potassium during cropping.

Soils No. 3 and 19, the Amity and Willamette soils from Washington County, were intermediate in both potassium release during cropping and also in the total amount of potassium removed by cropping. They differ from the Amity and Willamette soils in Benton County in that they appear to be older soils with more profile development and are more highly weathered. There is also the possibility that these soils have been influenced by the same volcanic ash overlay as those soils in Columbia and Multnomah Counties. Pratt (36, pp. 111-115) and others have explained the difference in potassium release from Iowa, Indiana, and Alabama soils on the basis of degree of weathering, the more highly weathered soils supposedly releasing smaller amounts of potassium from nonexchangeable forms during greenhouse cropping.

The Dayton soils, which are planasols, released less potassium during cropping than their drainage associates Amity and Willamette.

Since they are poorly drained and more highly weathered they would tend to release less potassium. This is in agreement with the results of other investigations (36, pp. 111-115) and 45, pp. 30-35).

Of the total potassium removed by cropping, 14 to 100 percent was derived from nonexchangeable forms. This further indicates that the potassium released from nonexchangeable forms during cropping plays an important role in the potassium nutrition of plants, especially on those soils having a low exchangeable potassium level.

The exchangeable potassium levels in the soils studied have covered a wider range than the soils used in previous studies. The values for potassium release from nonexchangeable forms during cropping also covered a wider range and were higher than those reported in previous work. There was a distinct grouping of the potassium release values. For the five soils derived from old alluvium and basalt residuum these values ranged from 631 to 933 pounds per acre and for the planasols and soils influenced by volcanic ash from 83 to 269 pounds per acre. None of the soils studied fell into the intermediate range of 269 to 631 pounds per acre of potassium release.

Exchangeable potassium before cropping was highly correlated with the total potassium removed by greenhouse cropping ($r = 0.852$). Similar relationships were found by Pratt (36, pp. 112-114, Schmitz, (45, pp. 30-35), and Pearson (32, pp. 306-309). However, the correlation coefficient expressing the relationship between exchangeable potassium before cropping and the amount of potassium released during cropping was very low (0.174) which is in agreement with the results of other investigations (32, pp. 305-308). Since the majority of the soils used in this study were low to medium in potassium release and since the exchangeable potassium levels before cropping varied considerably, one would expect a low correlation coefficient between exchangeable potassium before cropping and potassium release from nonexchangeable forms by cropping. The values for exchangeable potassium after cropping ranged from 116 to 234 pounds per acre which was much less than for exchangeable potassium before cropping (83-950 pounds per acre) and indicates that the exchangeable potassium drops to a minimum level after intensive cropping and that this level is similar for many soils regardless of the initial levels of exchangeable potassium. This is in agreement with the results of Hoagland and Martin (21, pp. 29-30). The correlation coefficient for the relationship between exchangeable potassium and potassium released from nonexchangeable forms during cropping was 0.725. Schmitz (45, pp. 58-59) also found that exchangeable potassium after cropping was more highly correlated with potassium release during cropping than was exchangeable potassium before cropping.

The amount of potassium released from nonexchangeable forms by nitric acid was highly correlated with the amount released by greenhouse cropping (0.937) which bears out the findings of previous investigations (36, pp. 115-117) and 43, pp. 121-122). Even though the acid released an average of 2.5 times as much potassium as was released by greenhouse cropping, and despite the fact that the mechanism of the release of potassium by nitric acid is not yet well understood, it still provides a rapid and reliable method for evaluating the relative ability of soils to release potassium from non-exchangeable forms during intensive greenhouse cropping.

The correlation coefficient between total potassium removed by ten successive cuttings of clover in the greenhouse and the total amount of potassium extracted by nitric acid was highly significant (0.959). Thus it appears that the relative amounts of potassium removed by Ladino clover in the greenhouse from soils of the same general characteristics as these studied here, can be predicted quite accurately by extraction with boiling, normal nitric acid.

In the field, however, there is a more complex situation. Factors such as aeration, subsoil conditions that influence the volume of soil from which potassium is absorbed by plants, supply of potassium in the subsoil, and supply of other nutrients influence the absorption of potassium by plants. For accurate prediction of potassium removal by plants under field conditions these factors must be measured and included with chemical evaluation of the potassium fertility of the surface soils.

The amount of potassium removed in six harvests was nearly as highly correlated with the total potassium in the nitric acid extract as that removed in ten harvests. These correlation coefficients were 0.936 and 0.959 respectively. These results indicate that for soils similar to the soils in this study, a shorter cropping period that has been commonly used in previous studies is adequate. This is further born out by the fact that the potassium uptake in 15 of the 20 soils had leveled off to very low amounts by the sixth harvest, or 175 days of cropping.

Since three harvests of clover in the greenhouse would be somewhat comparable to the growth during a season in the field the correlation coefficient for exchangeable potassium before cropping and potassium removed by three harvests in the greenhouse was determined. This correlation coefficient was 0.961 which was highly significant and indicates that exchangeable potassium levels in these soils before cropping is a reliable index of the potassium removed during short periods of cropping.

Randomly selected soil samples

The data from the chemical analyses for various forms of potassium in the randomly selected soil samples from 100 sites in Western Oregon are in agreement with the results of the greenhouse trial. The soil derived from loess-volcanic ash were significantly lower in acid releaseable potassium than the soils derived from old alluvium, and basalt residuum with the exception of the planasol soils derived from this material.

The Amity and Willamette soils in Washington County again were slightly lower in potassium released by nitric acid than those in Benton County. The Dayton soils were lower in potassium release than their drainage associates as was the case in the greenhouse trial.

The data indicates that exchangeable potassium and potassium release by nitric acid are somewhat independent of each other the correlation coefficient being only 0.30 for the surface six inches. This relationship varied for the individual soil series. The correlation coefficients for the relationship between exchangeable potassium and potassium release by nitric acid ranged from -0.80 to +0.86. There was no ready explanation for these differences between soil series since the soils with similar correlation coefficients did not fall into the same range as far as potassium release was concerned, nor was the degree of correlation related to parent material. Ten samples may not be an adequate number for determining correlation coefficients. Pratt (38, pp. 17-19) felt that the most probable cause for variations in potassium release within a soil series was the variation in the potassium content of parent material and degree of weathering.

The correlation between exchangeable potassium in the three depths sampled was highly significant but not quite as high as the correlation coefficients between potassium release from nonexchangeable forms by nitric acid in the three depths. The fact that the potassium release values for the three depths were slightly better correlated than the exchangeable potassium values is another indication that potassium release is more characteristic of the soil series than exchangeable potassium.

Profile samples

The values for exchangeable potassium and potassium release from nonexchangeable forms by nitric acid extraction from the profile samples generally decreased with depth. A few exceptions to this general trend were noted. Both exchangeable potassium and potassium release dropped off in the A_{21g} and A_{22g} horizon of the Viola and so called Amity profiles and increased again in the B horizon. Since the A_2 horizons are highly leached the potassium values for these horizons would tend to be lower than those for the less leached horizons.

Some of the other deviations from the general trend of decreasing exchangeable and acid releaseable potassium with depth occurred where definite profile discontinuities existed. Evidence of profile discontinuities was obtained from the results of the mineralogical studies which indicated distinct differences in degrees of weathering and in parent material within some of the profiles.

The soils derived from old alluvium and basalt residuum did not decrease as rapidly with depth in exchangeable potassium and potassium release as did the soils derived from loess and volcanic ash. The planasols were lower in potassium release than their better drained associates, as would be expected.

No explanatory relationship was established between the general order of potassium supplying capacities of the various horizons in the profiles and such properties as amount of silt or clay, or amount of mica, vermiculite, chlorite, koalin, montmorillonite, or quartz in the clay fraction. This is in agreement with the results of Reitemeier et al (42, pp. 39-40) who stated that the absence of any obvious relationship between the extent of potassium release and the content of hydrous micas or potassium bearing minerals did not mean that the potassium behavior of the soils was not related to their mineralogical characteristics. They concluded that the usual methods of estimating mineral contents should be supplemented by determination of the actual potassium content and behavior of minerals as they exist in the soils.

It should be remembered that this study included only a few of the important agricultural soils in Oregon. Similar studies should be conducted on soils with different characteristics in order to evaluate the reliability of nitric acid extraction as an index to predict the relative potassium supplying power over a wider range of soils. Field fertility trials, to measure the response to potassium fertilizer, should also be conducted in order to establish levels for acid extractable potassium which would aid in a better interpretation of the results of a chemical evaluation of the potassium status of the soils. More adequate mineralogical studies are needed to obtain a better understanding of the factors affecting the release of potassium from moderately available to available forms.

SUMMARY AND CONCLUSIONS

Three related studies were conducted in this investigation:

1. Soils from twenty sites representing seven soil series in Western Oregon were intensively cropped with Ladino clover in the greenhouse. Exchangeable potassium, potassium released from non-exchangeable forms during cropping, and total potassium removed by cropping were determined and correlated with the potassium released from nonexchangeable forms by extraction with boiling normal nitric acid, and the total potassium in the nitric acid extract.

2. Exchangeable potassium, potassium released from nonexchangeable forms by boiling normal nitric acid, and total potassium in the nitric acid extract were determined on soil samples from 100 randomly selected sites in Western Oregon. These samples represented six soil series and each site was sampled at three depths, 0-6, 6-12, and 12-18 inches. The standard error of the mean was calculated for individual soil series and the L.S.D. was determined for all soils (100 samples) at the three depths. Correlation coefficients expressing the relationship between the different forms of potassium in individual soil series and in all soils (100 samples) were also determined.

3. Exchangeable potassium, potassium released from nonexchangeable forms by boiling normal nitric acid, and total potassium in the nitric acid extract were also determined for soil samples from the various horizons of eleven profiles representing six soil series. An attempt was made to relate the potassium status of the various

horizon to such characteristics as silt and clay content and the quantity of certain minerals in the clay fraction of these horizons.

The most significant results of this study were as follows:

The soils included in this study varied tremendously in the amount of potassium released from nonexchangeable to exchangeable forms during greenhouse cropping and by extraction with boiling normal nitric acid.

Differences in potassium release from nonexchangeable forms and in potassium supplying power appeared to be related to differences in parent material and in degree of weathering. The soils derived from loess and volcanic ash were lower in both potassium release and potassium supplying power than the soils derived from old alluvium or basalt residuum. The planosols were lower in potassium release and potassium supplying power than the less highly leached and better drained associates.

Exchangeable potassium before cropping was highly correlated with the amount of potassium removed in ten harvests of Ladino clover ($r = 0.852$).

Exchangeable potassium before cropping and potassium release from nonexchangeable forms during cropping appeared to be independent of each other since the correlation coefficient for this relationship was only 0.174, which was not significant.

The potassium released from nonexchangeable forms during cropping was highly correlated with the potassium released from nonexchangeable forms by nitric acid ($r = 0.937$).

The total potassium removed in ten successive cuttings of Ladino clover in the greenhouse was very highly correlated with the total potassium in the nitric acid extract (r = 0.959).

The total potassium removed in six successive cuttings of Ladino clover in the greenhouse was almost as highly correlated with the total potassium in the nitric acid extract, (r = 0.936), as that removed in ten cuttings (r = 0.959).

The total potassium in the nitric acid extract was the most reliable index for predicting potassium removal by intensive greenhouse cropping with Ladino clover on soils with the general characteristics of those studied here.

Exchangeable potassium and potassium released from nonexchangeable forms in the soil samples from 100 randomly selected sites were relatively independent of each other. The correlation coefficient for this relationship was very low. There was a wide variation in these correlation coefficients for individual soil series.

The correlation coefficients for the relationship between exchangeable potassium in the 0-6, 6-12, and 12-18 inch depths of the soil samples from 100 randomly selected sites were high but not as high as those for the relationship between potassium released from nonexchangeable forms by nitric acid in these three depths.

There was no apparent relationship between the amount of soil or clay or the amount of certain minerals in the clay fraction of the various horizons of the profile samples and the amount of potassium released from nonexchangeable forms by nitric acid.

This investigation initiated a survey of the potassium supplying power of certain Oregon soils. Additional work, of the nature reported here, is needed to obtain this information for more of the major agricultural soils in the state. The rather high correlation between total potassium in the nitric extract and the potassium removed by intensive greenhouse cropping indicates that this chemical method is a reliable index to the potassium supplying power of soils with the general characteristics of those studied here, and suggests the use of this method in any additional work of this nature. In order to make the best use of the results of this study, the relationship between both exchangeable potassium and potassium release from nonexchangeable forms by nitric acid extraction and the response to potassium fertilizers needs to be more fully investigated.

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APPENDIX

Table XII. Principal morphological characteristics of the horizons of eleven profiles

Profile No.	Horizon	Depth in inches	Munsell color notation (moist)	pH	Texture	Structure	Consistence
S53-Ore-26-1 Amity	A_{11}	0-4	10YR 3/1	5.1*	sil**	3mgr**	wps**
	A_{12g}	4-11	10YR 3/1	5.1	sil	3mgr	wps, dh
	A_{21g}	11-16	10YR 3/2	5.1	sil	2fsbk	mfi, dh
	A_{22g}	16-19	10YR 5/2	5.0	sil	1msbk	wps, mvfr, dh
	B_{2gt}	19-29	10YR 4/2	4.6	sicl	3vcpr	mfi, dvh
	B_{2m}	29-38	5Y 5/2	4.9	sicl	----	wp, mfr, dh
	B_3	38-48	5Y 5/2	5.4	sil	----	wps
	C_1	48-66	5YR 4/6	5.5	sil	sg	wps
	C_2	66-88	10YR 5/3	5.2	vfsl	sg	wpo, dl
S53-Ore-26-2 Powell	A_1	0-5	10YR 3/2	5.2	sil	2mgr	wp, mfr, dsh
	A_3	5-12	10YR 4/3	5.3	sil	2cgr	wps, mfr, dsh
	B_{21}	12-20	10YR 5/3	5.3	sil	1fsbk	wps, mvfi, dsh
	B_{22m}	20-33	10YR 5/4	5.1	sil	1fsbk	wps
	B_3	33-45	10YR 5/4	5.2	sil	1msbk	----
	C_1	45-60-	10YR 8/2	5.3	sil	m	wpo, mfi
S53-Ore-26-3 Powell	A_1	0-4	10YR 3/3	5.6	sil	3fgr	wps, mfr, dsh
	A_3	4-11	10YR 4/4	5.7	sil	3mgr	wps, mfr, dsh
	B_1	11-20	10YR 4/4	5.7	sil	1msbk	wps, mfr, dsh
	B_2	20-29	10YR 5/3	5.5	sil	1msbk	wps, mvfi, dh
	B_{31}	29-36	10YR 5/3	5.3	sil	1csbk	wps, mvfi, dvh
	B_{32}	36-50	10YR 5/3	5.3	sil	1csbk	wps, mvfi, dh
	C	50-70	10YR 5/3	5.6	sil	m	wps, mvfi, dh

* pH determined in laboratory with glass electrode.
**Abbreviations are those used in Soil Survey Manual, Agric. Handbook No. 18, pp. 139-140.

Table XII. Con't. Principal morphological characteristics of the horizons of eleven profiles.

Profile No.	Horizon	Depth in inches	Munsell color notation (moist)	pH	Texture	Structure	Consistence
S53-Ore-26-4 Powell	A_1	0-4	10YR 3/2	6.3	sil	3fgr	wps, mfi, dsh
	A_3	4-15	10YR 3/3	6.2	sil	3cgr	wps, mfi, dsh
	B_1	15-23	10YR 4/6	5.5	sil	2msbk	wps, mvfi, dh
	B_{21}	23-35	10YR 4/6	5.5	sil	2msbk	wp, mvfi, dh
	B_{22}	35-52	10YR 4/6	5.2	sil	2csbk	wp, mvfi, dh
	B_3	52-	10YR 5/6(dry)	5.2	vfsl	m	----
S53-Ore-5-1 Cascade	A_1	0-2	10YR 3/2	6.0	sil	cgr	wps, mfi, dsh
	A_3	2-8	7.5YR 4/4	5.7	sil	vcgr	wps, mfi, dsh
	B_1	8-17	7.5YR 4/4	5.5	sil	msbk	wps, mfi, dsh
	B_{21}	17-27	7.5YR 4/4	5.4	sil	msbk	wps, mfi, dsh
	B_{22m}	27-48	7.5YR 4/4	5.2	sil	pr	----
	B_3	48-61	10YR 4/4(dry)	5.1	sicl	cbk	wp
	D_1	61-75	2.5YR 3/6(dry)	5.0	c	csbk	wp
S53-Ore-5-4	A_1	0-3	7.5YR 3/2	6.2	sil	2mgr	wpo, mfi, dsh
	A_3	3-12	5 YR 4/3	6.2	sil	2cgr	wps, mfi, dh
	B_1	12-23	5YR 4/3	5.8	sil	2csbk	wps, mfi
	B_{21}	23-36	7.5YR 5/6	5.4	sil	2csbk	wps, mefi, dvh
	B_{22}	36-49	7.5YR 5/6	5.7	sil	----	----
	B_{3m}	49-63	7.5YR 5/6	5.7	sil	----	----
	C_1	63-79	7.5YR 4/4	5.7	sicl	2csbk	wp, mfi, dh
	C_2	79-89	7.5YR 5/4	5.3	sicl	msbk	----
	D_{12}	89-101	5YR 4/6(dry)	5.4	sic	vcsbk	----

Table XII Con't. Principal morphological characteristics of the horizons of eleven profiles

Profile No.	Horizon	Depth in inches	Munsell color notation (moist)	pH	Texture	Structure	Consistence
S53-Ore-5-2 Viola	A_{11g}	0-4	10YR 4/2	5.0	sil	1mpl	wps, mvfr, ds
	A_{12g}	4-10	10YR 4/2	5.0	sil	2cgr	wps, mvfr, ds
	A_{21g}	10-19	10YR 4/2	5.3	sil	2msbk	wps, mfi, dh
	A_{22g}	19-26	10YR 6/3	5.0	sil	1mpl	wp, mfi, dh
	B_{2tg}	26-39	2.5Y 6/2	4.8	sicl	3cpr	wvp, mfi, dh
	B_{22g}	39-49	2.5Y 6/2	5.2	sic	m	wvp, mfi, dh
	B_3	49-59	5Y 6/1	5.3	sic	1msbk	wp
	C_1	59-71	5Y 6/1	5.3	c	m	wp
S53-Ore-5-3 Viola	A_1	0-3	10YR 4/2	4.8	sil	1vfgr	wps, mfi, dh
	A_{21g}	3-9	2.5Y 5/2	5.1	sil	m	wps, mfi, dh
	A_{22g}	9-23	2.5Y 5/2	5.6	sil	m	----
	B_{1g}	23-35	2.5Y 5/2	5.6	sicl	3cpr	wp, mfi, dvh
	B_{21g}	35-45	2.5Y 5/2	5.5	sicl	--	wvp, mfi, dvh
	B_{22g}	45-61	2.5Y 5/2	5.4	sicl	--	wvp, mfi, dvh
	C_g	61-81	2.5Y 5/2	5.4	sic	--	wp, mfi, dh
Amity Benton Co.	A_1	0-13	10YR 4/2	5.8	sicl	2mgr	mvfr
	B_1	13-26	10YR 4/2	5.3	sicl	2msbk	mfr
	B_2	26-36	10YR 5/3	5.3	sic	2csbk	mfi
	C_1	36-40	10YR 6/2	5.2	sicl	2mfsbk	mfr

Table XII Con't. Principal morphological characteristics of the horizons of eleven profiles.

Profile No.	Horizon	Depth in inches	Munsell color notation (moist)	pH	Texture	Structure	Consistence
Dayton	A_1	0-12	10YR 6/2	5.2	sil	1fgr	mfr
Linn Co.	A_2	12-13	10YR 6/1	5.3	sicl	1fgr	mvfr
	B_2	13-30	10YR 6/2	5.5	sic	3cpr	wp
	B_3	30-38	10YR 6/2	6.3	sicl	2msbk	mfi
	C_1	38-60	10YR 6/3	6.8	sil	1fsbk	mfr
	C_2	60-80	10YR 6/3	6.7	sil	1fsbk	mfr
Willamette	A_1	0-10	10YR 4/3	6.1	sicl	2mgr	mvfr
Benton Co.	B_2	10-32	10YR 5/3	5.3	sic	2fsbk	mfi
	C	32-60	10YR 5/3	5.1	sicl	1fsbk	mfr

Table XIII. Yield of clover at different harvests - grams dry matter per can

Soil No.	Harvest No. 1	2	3	4	5	6	7	8	9	10	Roots	Total
1	6.27	8.62	8.78	7.58	11.87	6.37	7.34	9.39	7.34	10.35	8.69	92.60
2	3.65	5.52	5.98	5.70	8.51	5.49	6.97	8.34	6.47	10.90	9.50	77.03
3	4.67	6.00	4.33	3.43	5.15	2.89	2.50	2.70	2.31	6.35	3.17	43.50
17	6.18	8.43	8.40	6.99	11.03	6.92	7.51	9.10	6.24	9.31	8.08	88.19
18	4.88	6.85	7.98	6.28	9.97	6.67	6.70	7.87	6.19	9.60	5.53	78.52
19	4.05	5.22	4.90	3.60	5.10	3.69	3.25	3.05	2.81	5.53	3.47	44.67
11	2.25	4.32	4.63	4.41	6.99	4.47	5.02	7.12	5.61	7.67	7.10	59.59
12	4.83	5.83	4.87	3.51	3.89	2.00	2.10	2.21	1.71	6.73	4.39	42.07
4	4.90	6.43	5.85	5.53	7.71	3.67	2.41	2.05	1.50	8.80	4.55	53.40
5	6.08	7.55	6.38	5.01	6.78	2.74	1.65	1.81	1.21	8.31	4.34	51.87
6	3.65	3.00	2.55	2.13	2.27	1.39	1.40	1.49	1.17	5.60	2.35	27.00
7	5.82	7.05	5.80	4.50	5.45	2.67	2.75	2.80	1.95	6.37	3.88	49.04
13	6.65	8.32	7.83	7.53	9.51	4.60	3.55	4.55	2.61	8.59	4.17	67.91
14	5.27	5.92	6.48	5.08	5.11	3.35	2.58	3.51	2.34	7.03	4.81	51.48
15	3.53	4.05	3.60	2.60	2.83	1.99	1.69	1.75	1.65	5.14	4.81	33.64
16	4.83	6.93	5.75	5.07	4.52	3.85	2.38	2.75	2.15	7.85	3.57	48.65
8	3.70	4.75	3.85	3.10	3.61	1.97	2.11	2.06	1.95	5.41	2.93	35.44
9	2.98	5.10	4.58	4.63	5.55	3.19	3.39	3.85	2.74	7.77	3.45	47.23
10	4.52	4.88	4.38	3.15	3.90	2.80	2.11	2.31	2.00	5.07	3.17	38.29
20	4.73	3.85	2.85	2.30	2.19	1.61	1.10	1.09	0.90	6.77	0.70	28.09

Table XIV. Percent K in clover at different harvests.

Soil No.	Harvest No. 1	2	3	4	5	6	7	8	9	10	Roots
1	3.5	4.4	2.3	1.9	1.4	1.9	1.2	0.9	1.0	0.6	0.2
2	3.6	4.2	2.3	2.1	1.6	2.4	1.7	1.3	1.5	1.0	0.3
3	1.0	1.0	0.7	0.6	0.5	0.6	0.5	0.3	0.5	0.2	0.3
17	3.6	4.5	2.2	1.9	1.5	2.0	1.4	1.1	1.3	0.7	0.3
18	3.5	4.7	2.8	2.1	1.7	2.5	1.7	1.3	1.5	0.7	0.4
19	1.1	1.2	0.7	0.6	0.5	0.7	0.5	0.4	0.6	0.3	0.2
11	3.7	5.2	3.3	2.7	2.1	3.5	2.4	1.8	1.9	1.3	0.7
12	1.6	1.3	0.7	0.5	0.4	0.5	0.4	0.3	0.4	0.2	0.2
4	3.3	3.4	1.6	0.9	0.7	0.6	0.4	0.4	0.4	0.2	0.2
5	3.0	3.0	1.4	0.9	0.7	0.6	0.5	0.3	0.4	0.2	0.2
6	0.7	0.6	0.4	0.3	0.3	0.4	0.3	0.3	0.3	0.2	0.2
7	2.6	2.6	1.2	0.8	0.5	0.7	0.5	0.3	0.4	0.2	0.1
13	3.0	3.2	1.6	1.0	0.6	0.6	0.5	0.4	0.4	0.2	0.2
14	2.1	1.6	0.7	0.4	0.3	0.4	0.3	0.3	0.3	0.2	0.1
15	1.0	0.7	0.4	0.4	0.3	0.4	0.3	0.3	0.4	0.2	0.1
16	2.1	1.9	0.9	0.5	0.4	0.5	0.4	0.3	0.4	0.2	0.2
8	0.9	0.8	0.5	0.4	0.4	0.5	0.4	0.3	0.4	0.2	0.2
9	0.9	0.9	0.7	0.7	0.5	0.9	0.7	0.5	0.6	0.2	0.2
10	1.1	1.0	0.6	0.5	0.4	0.6	0.4	0.3	0.4	0.2	0.2
20	0.6	0.6	0.4	0.3	0.3	0.3	0.3	0.2	0.3	0.1	0.2

Table XV. Cumulative uptake of K in greenhouse trial - PP2M

Soil No.	Harvest No. 1	2	3	4	5	6	7	8	9	10	Roots
1	193	541	719	848	995	1104	1181	1251	1318	1369	1371
2	114	320	440	544	662	778	878	974	1061	1158	1160
3	42	94	121	139	159	175	185	193	203	216	224
17	193	527	692	806	955	1076	1168	1257	1326	1382	1400
18	149	432	621	736	882	1032	1133	1222	1306	1369	1387
19	40	92	123	143	165	186	201	210	226	242	249
11	74	272	407	511	643	782	889	1002	1097	1189	1231
12	70	136	165	179	192	202	208	214	220	228	235
4	143	334	414	459	502	521	529	537	542	559	567
5	161	360	438	480	521	535	542	547	552	565	572
6	20	36	44	50	55	60	63	67	70	77	80
7	132	279	346	378	404	420	431	440	448	460	466
13	174	408	516	578	630	655	671	695	705	723	731
14	94	177	215	234	251	263	272	280	287	298	305
15	29	55	68	77	85	93	98	102	107	114	120
16	93	208	252	275	291	305	314	322	330	342	348
8	29	61	77	89	101	110	118	124	132	142	148
9	22	64	94	121	146	173	193	210	226	240	246
10	44	86	108	120	133	147	155	161	169	179	184
20	25	45	54	60	66	71	74	76	78	86	88