AN ABSTRACT OF THE THESIS OF

Vernon C. Bushnell for the Ph. D. in Ag. Chem. & Soils
(Name) (Degree) (Major)

Date Thesis presented April 1939

Title Potassium Availability in Some Oregon Soils

Redacted for Privacy

Abstract Approved:
(Major Professor)

This study was made to find siutable laboratory methods for the determination of available potassium; to describe their efficiencies, if possible; and to begin a preliminary survey of Oregon for soils deficient in potassium.

In a brief historical review a rather complete list of common primary soil minerals is arranged in the order of their decreasing rates of potassium availability. This list was compilied by the author from many sources. A somewhat extensive study of the literature was also made with respect to proper nutrient ratios, the results being tabulated along with their autherities. With water cultures the following average mol ratios were found:

N	P	K	Ca	Mg
100	9	45	28	7

For soils the N : P : K becomes roughly 2 ; 1 : 1 as verified experimentally.

Methods available for such studies are briefly dis-

cussed, namely, field methods, greenhouse methods, biological methods in the laboratory, and the Morgan and Neubauer methods. Alterations of the Neubauer method are thoroughly explained. Where A.O.A.C. methods could not be used the special methods substituted are described. Photo micrographs were made of the potassium and sodium precipatates used, and a discrepancy noted in the formula of sodium zinc uranyl acetate as given by Chamot and Mason.

By use of the rapid tests of the Morgan system the surface samples of many of the profiles were anaylsed for available nutrients. These results were tabulated by soil series grouped into recent alluvial, old valley filling, residual, arid, and peat soils.

An extensive study of potassium availability was made using the Neubauer method on twenty-five profiles representing more than one hundred samples. The results are tabulated in mg. per 100 gms. of dry soil, lbs. per acre, and by "crop rating" as according to a table derived from a review of the literature for Neubauer limiting values. The crop rating of the Neubauer study compares well with similar values by the Morgan method except for the Chehalis, Columbia, and Yakima series. The first two series are low by the Morgan method, while the latter is high.

A detailed study was made with the Newberg, Chehalis, Powell, Yakima, Lake Labish and Feaselman peat soils. With the exception of the Chehalis series, where the field trials were not of a type suitable for a comparative study of methods, the field trials, greenhouse methods, and chemical estimations agree very well. With the exception of the Chehalis and Yakima series all are deficient in potassium, and respond to treatment with that element.

Along with tables and photographs there is a bibliography. Two color plates are shown pointing out the effect of potassium fertilization on beans on Lake Labish peat.

POTASSIUM AVAILABILITY IN SOME OREGON SOILS

by

VERNON CLIFFORD BUSHNELL

A THESIS

submitted to the

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

April 1939

APPROVED:

Redacted for Privacy

Head of Department of Soils

In Charge of Major

Redacted for Privacy

Chairman of School Graduate Committee

Redacted for Privacy

Chairman of State College Graduate Council

ACKNOWLEDGMENT

The author wishes to thank the American Potash Institue and the Soils Department at Oregon State College for the financial aid necessary to carry on this study. He also wishes to thank individually: Dr. W. L. Powers for work in directing the research for, and composition of, this thesis; Professor J. S. Jones and Dr. W. M. Atwood for technical advice; and my wife who assisted with much of the routine of the research and work on the manuscript.

TABLE OF CONTENTS

Section	Page
Introduction	1
Historical	2
Experimental	10
Methods of Detecting Potassium Deficiency	10
General Soil Studies	18
Special Soil Studies	24
Newberg Series	24
Chehalis Series	26
Powell Series	27
Yakima Series	27
Lake Labish Peat	28
Feaselman Peat	32
Summary	36
Bibliography	

ILLUSTRATIONS

		Following Page
Table I.	Relative Availability of Mineral Potassium	3
Table II.	Nutrient Ratios from the Literature	6
Table III.	Neubauer's Limiting Values in mg. per 100 gms. of Soil	14
Table IV.	Limiting Values for K_2O	14
Table V.	Exchangeable Potassium Compared to Neubauer Potassium	14
Plate I.	Figure 1 - $K_2NaCo(NO_2)_6 \cdot H_2O$ cubes Figure 2 - $NaUO_2(C_2H_3O_2)_3$ tetrahedra Figure 3 - Fig. 2. with a crystal of $NaZnUO_2(C_2H_3O_2)_5 \cdot xH_2O$ monoclinic polysynthetic twins Figure 4 - Fig. 3. with polarized light	17
Table VI.	Aeration Experiment at Optimum Moisture for Available Nutrients by the Morgan System	19
Table VII.	Fertilizer Needs as Found by Morgan's System for Potatoes	22
Table VIII.	A Comparison of Morgan and Neubauer Values for Available Potassium	23
Table IX.	A Fertilizer Trial with Potatoes on Newberg Sandy Loam	25
Table X.	A Summary of a Ten Year Fertilizer Study on Chehalis Loam with Potatoes	25
Table XI.	A Fertilizer Trial with Potatoes on Powell Silt Loam	27
Table XII.	A Fertilizer Trial with Potatoes on Yakima Fine Sandy Loam	27
Table XIII.	A Fertilizer Trial with Detroit Dark Red Beets on Lake Labish Peat	28
Plate II.	Lake Labish Beets Showing the Relative Growth and Yield of Several Plots	28

		Following Page
Plate III.	Beets Growing on Lake Labish	28
Plate IV.	Bean Leaves Grown on Lake Labish Unfertilized	28
Plate V.	Bean Leaf Grown on Lake Labish Fertilized with 3-10-10	28
Table XIV.	The Influence of Fertilizers on the Physiology of Beets (1937)	29
Table XV.	A Greenhouse Study with Beets on Lake Labish Peat	29
Plate VI.	Beets Growing on Lake Labish Peat	30
Plate VII.	Beets Harvested from Greenhouse Experiment	30
Plate VIII.	A Detailed View of Greenhouse Beets	30
Plate IX.	Cross Section of Beets from Greenhouse	31
Table XVI.	A Greenhouse Study with Rosen Rye on Lake Labish Peat	31
Table XVII.	Data on Radishes Grown in Jars of Lake Labish Peat	31
Plate X.	Rye in Greenhouse on Lake Labish Peat	31
Plate XI.	Plate X. continued	31
Plate XII.	Radishes from Greenhouse Experiment with Lake Labish Peat	31
Plate XIII.	Plate XII. continued	31
Plate XIV.	Plate XII. continued	31
Table XVIII.	Analyses of Greenhouse Jars of Lake Labish Peat after Cropping with Rye and Radishes	31
Table XIX.	Recovery of Potassium from Lake Labish Peat by Rye and Radishes	32
Table XX.	Data on Cranberries from Feaselman Peat	32

POTASSIUM AVAILABILITY IN SOME OREGON SOILS

INTRODUCTION

The defining of potassium availability is a task that has confronted soil scientists and agricultural chemists ever since Liebig's early work with synthetic fertilizers. Much discussion has occurred as to how, and in what form, plant nutrients may be taken up by plant roots. The manner and rate in which nutrients are made available to plants have never been completely answered. Correlation of findings for soils of one locality with those of another, or for different samples within the same series, is imperfect.

The specific object of this study has been to find suitable laboratory methods for the determination of available potassium; to describe their efficiencies if possible; and to begin a preliminary survey of the State for potassium deficient soils.

HISTORICAL

It is not sufficient to define available potassium as being that portion of an element which may be assimilated by a plant. As a soil undergoes progressive decomposition, at some time each part of the soil potassium must be at least temporarily available, specifically water soluble. Otherwise, neither the secondary minerals of a mature soil, nor the inert colloids of the laterites and podsols, could have been formed. As Sante Mattson and J. B. Hester (1933) have shown a primary mineral will be more stable if its isoelectric point corresponds with the pH of the soil, and the secondary minerals formed will be of such a ratio as to $SiO_2 : R_2O_3$ that their isoelectric points will likewise correspond to the pH of the soil. The pH in turn depends on climatic and biological factors which together ultimately control the genetic development of all soils. This explains how soils well matured may still contain some primary minerals, yet eventually complete disintegration must result, and all portions of the potassium pass through a stage where it would be available.

Ultimate availability is not what a soil chemist has in mind when he thinks of available potassium. What he is thinking of is the amount of assimilatable potassium liberated by the soil during each growing season, the laws that govern such availability, and the methods of determining this quantity.

A simple equation to express the way potassium is made available might be written as follows:

$$K\ mineral \rightleftarrows H_2O\ soluble\ K^+ \rightleftarrows K\ colloid$$

The only form in which potassium can be assimilated by plants is that of a cation in water. The above equation fails, however to show the difference in the rates at which potassium ions are liberated from the mineral and colloid. It appears that the K mineral liberates the cations faster than the K colloid, but actually the reverse is true. The colloid can liberate potassium ions so rapidly, if the water soluble portion is depleted, that the potassium sorbed (held by either adsorption or absorption) by the colloid is also considered available.

After an extensive review of the literature the common K minerals were arranged in Table I in order of their decreasing ability to liberate potassium ions. The process of decomposition of a potash mineral consists of at least two steps. Using the classical example of orthoclase (which is a poor selection as far as the rate of decomposition is concerned) the following equations can be proven correct:

TABLE I

RELATIVE AVAILABILITY OF MINERAL POTASSIUM*

Mineral	System	Formula
Very High		
Nephelite	hexagonal	$(K,Na)AlSiO_4$
Biotite (mica)	monoclinic	$KH_2(Mg,Fe)_3Al(SiO_4)_3$
Phlogopite (mica)	monoclinic	$KH_2Mg_3Al(SiO_4)_3$
Sericite (mica)	monoclinic	$KH_2Al_3(SiO_4)_3$
High		
Plagioclase	triclinic	$NaAlSi_3O_8$ to $CaAl_2(SiO_4)_2$
Phillipsite	monoclinic	$(K_2,Ca)Al_2(SiO_3)_4 \cdot 4\frac{1}{2}H_2O$
Muscovite (mica)	monoclinic	$KH_2Al_3(SiO_4)_3$
Elaeolite	hexagonal	$(K,Na)AlSiO_4$
Medium		
Leucite	isometric	$KAl(SiO_3)_2$
Glauconite	colloid	A K, Fe hydrated silicate
Apophyllite	tetragonal	$KF \cdot Ca_4(Si_2O_5) \cdot 8H_2O$
Poor		
Sanidine	monoclinic	$NaAlSi_3O_8$
Orthoclase	monoclinic	$KAlSi_3O_8$
Microcline	triclinic	$KAlSi_3O_8$
Toxic		
Lepidolite	monoclinic	$KLi(F,OH)_2Al_2Si_3O_{10}$

* Compiled from many sources.

$$(1)\ K_2O.Al_2O_3.6SiO_2 + H_2CO_3 \longrightarrow H_2O.Al_2O_3.6SiO_2 + K_2CO_3$$

$$(2)\ H_2O.Al_2O_3.6SiO_2 + 9H_2O \longrightarrow Al_2O_3.2SiO_2.2H_2O + 4H_4SiO_4$$

The first reaction is a typical example of double decomposition or double replacement and is closely related to the "Base Exchange" reactions with colloids, which will be explained later. The second reaction is purely a hydrolytic reaction where an acid and a somewhat more basic compound are produced. In alkali soils sodium silicate will be formed, but in acid or neutral soils the ortho silicic acid will dehydrate to silica.

The potassium liberated is now in a water soluble form and exists largely as a cation. Three things can happen to this ion: it can remain in solution, which a small amount does; it can be assimilated by plants; or, it can replace another cation on one of the colloids present:

$$nK^+ + M^{+n}(\text{colloid}) \rightleftarrows nK^+(\text{colloid}) + M^{+n}$$

This type of a reaction has been called "Base Exchange". Actually it appears to be a double decomposition reaction, and seems to follow the Law of Mass Action. The constants involved depend on the charge, definitely, and, according to some recent writers, the ionic volume.

In 1850 H. S. Thompson and Thomas Way published articles in the Jr. Royal Agr. Sci. (Eng.), vol. 1, No. 11, Thompson, pages 68 to 74, and Way, pages 313 to 379. They both found that soils absorbed NH_4^+ from $(NH_4)_2SO_4$ and that $CaSO_4$, in equivalent amounts, was leached out. Way found that NH_4, K, Mg, and Ca ions were absorbed from their salts and hydroxides in equivalent amounts by soils.

Not much work was done with base exchange studies until Professor K. K. Gedroiz began his series of papers extending from 1913 to 1926. Gedroiz established most of the theories and principles of base exchange now so familiar to soil scientists throughout the whole world.

Many recent developments have been made in the study of base exchange with respect to potash. S. Gericke (1928) fractionated a soil into particles of various sizes, and found that the particles less than 0.002 mm. in diameter contained most of the potassium of an exchangeable nature. M. Kling and O. Engels (1935) made over 1400 Neubauer tests and found that the probability of a potassium deficiency decreased as the clay content increased. Humus, an organic colloid, has a much higher sorption capacity than clay. E. E. Vanatta (1915) found that manure mixed with soil causes a decrease in water-soluble potassium.

One other factor that strongly controls the availability of any nutrient element is the relation of that element to all of the other nutrient elements available with respect to molecular ratios. Liebig's "Law of the Minimum" specifies that a plant can not continue to make normal growth after any one of the nutrient elements has been made unavailable (by dilution, adverse ratios, or otherwise). Plant physiologists have shown that not only do plants stop growing but that the absence of any nutrient element will cause a characteristic injury known as a "Deficiency Symptom". Potash deficiency symptoms are described and colored illustrations given in a recent book of that name by Eckstein, Bruno, and Turrentine (1937).

In 1911 O. Schreiner and J. Skinner of the Bureau of Soils, U. S. Dept. of Agr. published one of the earliest papers on nutrient ratios. Using wheat seedlings they showed that when the greatest growth occurred the solution suffered the least change in the ratio of the nutrient constituents although the greatest change in concentration took place. "The higher the amount of any one constituent in the solution the more does the culture growing in that solution take up this constituent, although it does not seem to be able to use this additional amount economically." These observations are very important as they show that the nutrient ratios in a plant showing optimum growth indicate the optimum nutrient ratios for the culture media. On this basis Table II was constructed, and an average mol ratio determined:

N	P	K	Ca	Mg
100	9	45	28	7

TABLE II

NUTRIENT RATIOS FROM THE LITERATURE

Crop	Mol Ratios					Authority
	N	P	K	Ca	Mg	
Ageratum	100	6	118	50	8	Norem, W. I. (1936)
Potatoes	100	5	39	14	6	Depardon (1937)
Rhubarb	100	13	58	32	5	Becker-Dillingen, J. (1938)
Wheat seedlings	100	8	36	-	-	Schreiner, O. and Skinner, J. (1911)
Sugar cane	100	5	25	-	-	Van der Honest, T. H. (1932)
Apple trees	100	8	23	-	-	Thomas, Walter (1933)
Various plants averaged	100	5	30	-	-	Rackmann, I. K. (1935)
Unspecified	100	10	30	-	-	Rackmann, I. K. (1936)
Average of legumes	100	21	-	-	-	Rohde, Gustav (1934)
Corn	-	9*	45*	-	-	Parker, F. W. and Pierce, W. H. (1928)
Various plants averaged	-	18#	45*	-	-	Mitscherlich, E. A., Von Boguslaswski, E., and Gutman, A. (1935)
Oats and beans, K-deficient	-	-	45*	32	9	
K-excess	-	-	45*	10	4	Godlewski, Emile (1923)
Average	100	9	45	28	7	

* Taken from average value for K.
# Not averaged in P.

It must be understood that any of the components of this ratio may be increased one hundred per cent and still give good growth.

The study of correct nutrient levels has been in progress for years. One of the earliest papers published involving potassium levels in water culture was that by O. Arrhenius (1927). He found that for the straw plants a concentration of less than six parts per million of potassium seems sufficient, while for the root plants and clover about twenty parts per million seems best. Nine parts per million of PO_4 seems to be sufficient for all plants except clover which needs thirty parts per million. Earl S. Johnston and D. R. Hoagland (1929) showed that tomatoes required about five parts per million potassium.

Many plant physiologists and soil scientists contend that water culture data can not be applied directly to the soil cultures. Nevertheless it is an advantageous method by which one can arrive at just what are the optimum nutrient conditions for plant growth. The error, if any, is not with the water culture; it is with the establishment of just which portions of the nutrients in a given soil are available, what are their ratios, and how much excess nutrient must be added to accommodate the "fixing" process. It is a common practice to apply nearly four times as much phosphate as theoretically needed to a soil because an average of seventy-five per cent of that applied will be fixed in a slowly available form.

D. R. Hoagland and J. C. Martin (1933) showed that some non-replaceable potassium was available, but too slowly to avoid a potash deficiency if depended upon alone. They found that there is a striking interrelationship between Ca, Mg, and K, but that crop growth is not limited by specific nutrient ratios. R. P. Hibbard (1927) showed that in general practice definite ratios of fertilizer salts were not required. It should be remembered that even water culture allows a large variation.

W. Thomas (1930) pointed out that when only two of the major elements N, P, and K are applied to an infertile soil the absorption of the third element is depressed, but with a fertile soil it is increased. A so-called balanced fertilizer will be perfectly satisfactory on a soil already balanced, but with a soil deficient in N, P, or K a loss of efficiency is sure to develop and sometimes an actual injury, as will be shown later.

Potassium can not be replaced by sodium to more than a slight extent according to J. Stoklasa (1915) and H. Heinrich (1928). Rubidium is antagonistic to potassium and can not replace it according to Julius Arndt (1922). K. Scharrer and W. Schropp (1933) found that corn is the only common plant for which iron is antagonistic to potassium. This is the basis of the Hoffer test for potash deficiency. With rice K. Shibuya and T. Torii (1935) found that K:Ca antagonism was greater than K:Mg, and was affected most by sulfate, less by chloride and least by nitrate. A solution of salts of the same degree of dissociation showed the strongest antagonism. With a properly balanced nutrient ratio these antagonisms are reduced to a minimum. Undoubtedly this is why optimum ratios do exist.

Radio active K^{41} may be necessary for plant growth, but according to K. Heller, C. L. Wagner, K. Peh and B. Mendlik (1932) it is not selected or concentrated by plants.

EXPERIMENTAL

METHODS OF DETECTING POTASSIUM DEFICIENCY

Severe cases of potash deficiency can be detected in the field by the characteristic physiological symptoms that develop in the crops. This method, however, fails to indicate very accurately the degree of deficiency, and does not develop at all in cases of mild deficiencies. Field trials with fertilizers where the yield is measured will show mild deficiencies if properly conducted. Unfortunately this latter method involves time factors and expense in handling that strongly reduces its value. So far as the study herein presented is concerned field trials have been used only as a check against laboratory and greenhouse methods.

Greenhouse tests such as the Mitscherlich pot test system may be classified as laboratory methods, but carry many of the same objections as the field trial method. They may be more expensive than field tests as they require a large amount of greenhouse space, heat and artificial light in the winter, and almost constant attention. When properly duplicated, however, they produce very reliable information.

Other purely biological tests for potash deficiency consist of the use of several species of Aspergillus molds and Azotobacter. These methods are fast, but apparently their reliability is strongly questioned. No use of them was made in this study.

The laboratory methods used in this study are essentially of these types: base exchange, extraction with solvents and subsequent microchemical determinations, and the semibiological method by Neubauer.

The Salgado method (1934) for determining base exchange, as used in this study, is as follows: ten grams of soil are leached on a small Büchner funnel with 500 ml. of normal ammonium acetate in ten portions. The leachates are made up to a standard volume, and stored for later analysis.

Another method used in this study to determine both sodium and potassium simultaneously is that by Amar Nath Puri (1935). Ten grams of soil are leached with 500 ml. of N/2 ammonium carbonate in five portions. The leachate is evaporated to dryness and the alkali carbonates dissolved in fifty per cent alcohol, and filtered. Evaporate the filtrate to dryness, add excess standard acid, bring to boiling and titrate with standard alkali using brom thymal blue indicator. Since even the humid Western Oregon soils contain exchangeable sodium, and due to the alkaline solution suspending the organic matter so that a potentiometric titration has to be used, this method proved to be no improvement over the ammonium acetate method.

Within the past decade several good "rapid" methods for the determination of fertilizer needs have been developed. The Thornton, Truog, and Morgan methods are probably the three most popular. Only that by M. F. Morgan (1937) has been used in this study primarily because of its scope. The procedures are too numerous to be discussed here, but they are very well presented in Connecticut Bulletin 392, March 1937.

Probably the best and most accepted method used today for the determination of available potash is that by H. Neubauer (1923). As this was the principal method used in this study the procedure in detail, which is similar to that recommended by S. F. Thornton (1935), is as follows:

Treat 15 to 20 grams of Rosen rye seeds with "Semesan Jr." and germinate between wet filter paper under inverted crystallizing dishes for 36 to 48 hours. In 120 mm. crystallizing dishes place 50 gm. of quartz sand and 100 gm. of air-dry soil (determine per cent moisture). Mix the sand and soil, level out and cover with a layer of 50 gm. of sand. On this layer spread 100 germinated seeds. Insert in the center a vertical tube 3 to 4 inches long to facilitate watering. Cover the seeds with 200 gm. of sand. Run two samples in duplicate and a blank substituting sand for soil. Add 60 ml. of distilled water to the blank and approximately 80 ml. to the samples. Place in a germinator at 20°C for 17 days. Remove the plants, washing the roots free from sand and soil; and ignite at 500 to 550°C until the organic matter is destroyed. Cool, wet carefully with hot distilled water, and wash onto a filter. Wash ten times with small quantities of hot water (this is comparable to the J. Lawrence Smith method, Am. J. Sci. [3] 1, 269, [1871]). The potassium carbonate passes into the filtrate which is acidified with HCl, made up to 500 ml., and stored for analysis.

Mitscherlich is the most severe critic of the Neubauer method. On the other hand most chemists regard it as a reasonably sound method. L. Smolik (1934) found a close relationship between it and results by electrodialysis. T. M. Bushnell (1935) reports a satisfactory agreement between it and 0.2 N HNO_3. D. R. Hoagland and J. C. Martin (1935) state that with California soils it gives somewhat higher results than the base exchange methods. S. F. Thornton (1936) agrees with Hoagland and Martin.

It is not surprising that the Neubauer values should be higher than the base exchange values. The rye seedlings have 17 days for their extraction while the exchange methods are usually carried out in only a few hours. If the Law of Mass Action has any control whatsoever on the rate of mineral decomposition it should speed up the process as rate of mineral decomposition it should speed up the process as soon as the plants deplete the water soluble and exchangeable portion. As a matter of fact these are probably never depleted because some soils, especially peats, can actually remove potash from the seedlings. In other words the blanks have more potash in them than the samples, producing a negative value. I. Kühn (1935) found that as the amount of soil used decreased the Neubauer value increased, indicating that more non-replaceable potash is made available. He found that roots could assimilate potash at a distance of 8 to 10 mm.

From both Tables III and IV it is evident that for potash the Neubauer limiting values vary with the crop. A general average may be determined, but such a value seems to be without importance. The authorities do not agree too well on limiting values for specific crops. Phosphorus, however, has a more regular series of limiting values, except for alfalfa which is high. The mol ratio of P:K is 1:9 compared to 1:5 for water cultures.

A wide variety of Oregon soils has been studies comparatively as shown in Table V. There seems to be no relation between water soluble plus exchangeable potassium and Neubauer available. A close examination, however, seems to show that in the Willamette series as the soil becomes more heavy the availability of non-replaceable potassium becomes lower. In other words the potash minerals

TABLE III

NEUBAUER'S LIMITING VALUES IN MG. PER 100 GM. OF SOIL*

Plant	P_2O_5	K_2O
Rye, wheat	5	15
Barley, oats	6	18
Red clover	5	25
Alfalfa	9	35
Potatoes	6	47
Sugar beets	6	42
Meadow grasses	7	38
Mangles	7	65
Average	6	36
P:K mol ratio	1	9

*From "Theory and Practice in the Use of Fertilizers", page 273, by F. E. Bear, (1929) John Wiley and Sons, Inc., New York City, New York.

TABLE IV

LIMITING VALUES FOR K_2O

Neubauer

Crop	Mg. per 100 gm. dry soil	Authority
Grains, grasses, etc	20	R. Thun (1930)
Root crops	35	
(minimum)	15	
Grain	30	M. Kling and O. Engels (1930)
Vegetables and clover	30	
Grapes	50	
Tobacco	50	
Pastures	30	
------	25	L. Gisiger (1934)
------	15	Kirsanov and others (1934)
Grains	18	F. E. Bear (1929)
Legumes	35	
Root crops	47	
Grasses	38	
Mangles	65	

Summary by crops

Grains	24	
Grasses	29	
Legumes	33	
Root crops	37	
Grapes	50	
Tobacco	50	
Mangles	65	

TABLE V

EXCHANGEABLE POTASSIUM COMPARED TO NEUBAUER POTASSIUM

Sample		M.E. per 100 gm. dry soil		
		Exchangeable		Neubauer
		Alone	Plus water soluble	
Peat (Feaselman)	0- 8"	0.70	1.02	0.33
Chehalis chocolate brown loam	0- 7"	0.62	0.72	0.97
	7-18"	0.64	0.71	1.04
	18-40"	0.55	0.62	0.86
Willamette brown S. Cl. loam	0- 7"	0.87	1.09	0.61
	7-20"	0.80	0.95	0.80
Willamette brown loam	0- 7"	0.75	0.91	0.49
Sifton Gr. sooty V. F. S. loam	0- 7"	0.49	0.74	0.70
Yakima F. L. sand 2 yrs. potatoes 2 yrs. alfalfa	0- 8"	0.70	0.79	0.49
	8-22"	0.90	1.02	0.83
	22-36"	0.88	0.97	0.89
Yakima F. L. sand 2 yrs. potatoes 6 yrs. alfalfa	0- 8"	0.41	0.46	0.72
	8-22"	0.71	0.93	0.89
	22-32"	0.62	0.86	0.92

are gradually converted to secondary clay minerals. According to results with peat and Sifton soils organic matter dilutes the potash mineral to a point where it becomes inadequate for supplying potash. The Chehalis series is young soil and apparently high yet in non-replaceable potash. Besides the natural factors, such factors as crop rotation seem to strongly influence the relationship between these two quantities. Samples of the Yakima series from adjacent fields show an inverted proportion between Neubauer and base exchange values. The rotation was changed from (1) potatoes two years, alfalfa two years, to (2) potatoes two years, alfalfa six years. The six years of alfalfa may have brought up potassium from the subsoil. In any event it seems that Neubauer available potassium includes more than just replaceable and water soluble potassium, but not all of the replaceable potassium.

The analytical methods used for calcium and magnesium were essentially those of the A.O.A.C. The $MgNH_4PO_4 \cdot 6H_2O$ was titrated, however, and not determined gravimetrically. This determination is a modification of one by G. A. Korzheniovskii (1936), and is made as follows:

Filter the $MgNH_4PO_4 \cdot 6H_2O$ on a Gooch crucible fitted with a disc of Whatman No. 42 filter paper, or a similar grade. Wash well with NH_4OH (1 to 10), then wash three times with 15 ml. portions of alcohol. Return the crucible to the beaker, add 25 ml. of water and an excess of standard HCl. Remove and rinse the crucible into the beaker. Back-titrate with standard NaOH to a methyl orange substitute endpoint. This indicator is made as follows:

methyl orange 1.0 gm.

zylene cyanol FF. 1.4 gm.

Dissolve in 500 ml. of 50% alcohol. The endpoint is a neutral gray at a pH of 3.9. The reaction is as follows:

$$MgNH_4PO_4 + 2HCl \longrightarrow MgCl_2 + NH_4H_2PO_4$$

The latter compound produces a buffer at about pH 3.9. The method has proven with standards to be accurate to about one part in two hundred.

The method used for sodium was a gravimetric modification of a method by A. Blenkinsop (1930). The solution for this determination is evaporated to dryness, 5 to 10 ml. of concentrated HNO_3 added, and again evaporated to dryness. The beaker is then ignited carefully over a burner to sublime the ammonium salts. After cooling the sides are washed down, 5 to 10 ml. of concentrated HCl are added and carefully evaporated to dryness. Thus the salts are mostly chlorides. Twenty-five milliliter of the reagent of zinc acetate and uranyl acetate in acetic acid, as directed, are added, and left to stand for 24 hours. The solution is then filtered on a weighed Gooch crucible and washed first with reagent, then with alcohol saturated with $NaZn(UO_2)_3(C_2H_3O_2)_9 \cdot 6H_2O$. After the crucible is dried it may be weighed. Weight of the salt multiplied by 0.01495 gives the weight of sodium. The method has an accuracy of about one part in a hundred.

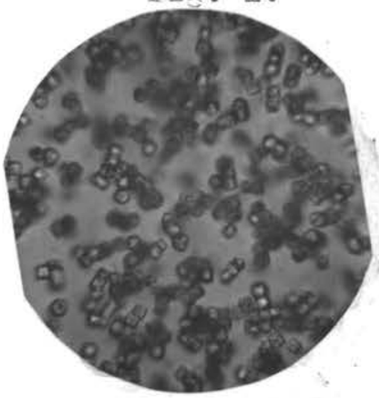
An interesting observation was made with a petrographic microscope concerning the order of precipitation of this salt, and its composition. The method is very similar to that used by Chamot and Mason (1931), but progresses (see Plate I) as follows:

Immediately upon adding the reagent tetrahedra of what Chamot and Mason call $NaUO_2(C_2H_3O_2)_3$ precipitate (figure II). Within a few minutes large monoclinic crystals begin to develop as the smaller tetrahedra dissolve away from them (figure III). These are anisotropic as shown in figure IV, and correspond perfectly to what Chamot and Mason call $NaZnUO_2(C_2H_3O_2)_5.xH_2O$.

Certainly after 24 hours the sodium content does not correspond to that formula, and it does correspond to $NaZn(UO_2)_3(C_2H_3O_2)_9.6H_2O$. The obvious conclusion to draw is that either there is a third order of crystals, or else Chamot and Mason are wrong as to the composition of their compound.

The most satisfactory general method for the determination of potassium both for speed and for accuracy is a modification of one by L. V. Wilcox (1937). As for sodium the ammonium compounds are removed, and the final residue is left largely as a chloride. As large amounts of calcium

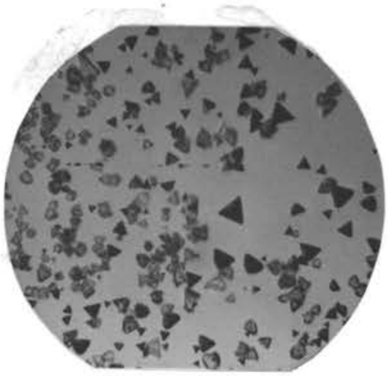
Fig. 1.



$K_2NaCo(NO_2)_6 \cdot H_2O$

Cubes

Fig. 2.



$NaUO_2(C_2H_3O_2)_3$

Tetrahedra

Fig. 3.

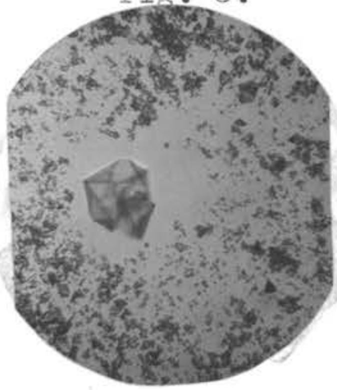


Fig. 2. with a crystal of $NaZnUO_2(C_2H_3O_2)_5 \cdot xH_2O$

Monoclinic polysynthetic twins

Fig. 4.

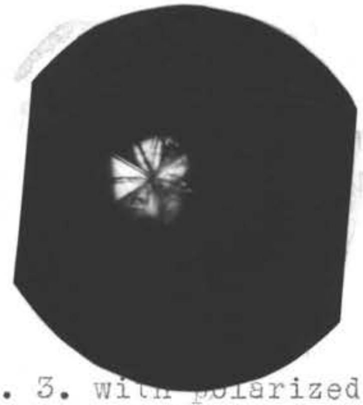


Fig. 3. with polarized light

Plate I

salts cause erratic results these must either be removed, or, as in the case of a plant ash, a hot water extraction may be used instead of a HCl extraction. Precipitate the potassium as directed by Wilcox, but wash as follows:

Wash the precipitate in the weighed Gooch crucible three times with 5 to 10 ml. portions of 0.01 N HNO_3 saturated with the precipitate. Wash three times with 15 ml. portions of methanol likewise saturated, then three times with either petroleum ether or diethyl ether. Dry about five minutes by suction, then 15 minutes at 105°C. Cool and weigh. The crystals are cubic, as shown on Plate I, figure I, with a composition of about 17.8 per cent potassium instead of 17.2 per cent as according to Wilcox. Those in figure I, however, are freshly precipitated, and correspond to the Wilcox formula. The dried compound is very nearly $K_2NaCo(NO_2)_6$. Without interference from calcium compounds this method has an accuracy of more than one part per hundred.

GENERAL SOIL STUDIES

The soils represented in this study consist of twenty-five profiles from a variety of common Oregon soil series. Western Oregon soils are classified as humid soils in spite of their usual drouthy condition in the summer. These soils can be divided into three main groups: (1) recent alluvial soils, (2) old valley filling soils, and (3) residual hill soils. Of the first group the Newberg, Chehalis, and Columbia series are represented; the second, Willamette, Salem, Sifton, and Waldo; and the third, Carlton, Melbourne, and Powell. Eastern Oregon soils are mostly arid. The Milton, Yakima, Nes Perce, Tumalo, Deschutes, and one labelled "Ditterline" of this group are included. In addition there are two peats and one sample labelled "Muck and Peat" included.

From a soil chemist's point of view the first step in the study of the fertilizer requirement of a soil is to try to establish a rather complete picture of the nutrient relationships occurring normally therein. This can be done easily and rapidly with a fresh sample by the Morgan system. With the exception of the sulphates the availability of all of the major mineral nutrient elements can be estimated with fair accuracy.

Air-dry samples were wetted to 80 per cent moisture equivalent, aerated for two weeks at room temperature, and available nutrients determined by rapid methods. A fairly good duplicate of field conditions was obtained as shown in Table VI.

In Table VI the samples of soil used are grouped for comparison from the young Newberg series to the old hill soils. The Milton and Yakima series are Eastern Oregon

TABLE VI

AERATION EXPERIMENT AT OPTIMUM MOISTURE FOR AVAILABLE NUTRIENTS BY THE MORGAN SYSTEM

No.	Sample		Lbs. Nutrient Per 2,000,000 Lbs. Soil										pH at	pH at
			NO_3 N	NH_3 N	P	K	Ca	Mg	Al	Mn	Fe^{+3}	Fe^{+2}	Opt. Moist.	1:5 Dil.
17a	Newberg S.L. (Pflageman)	0-7"	80	10	40	*150	4000	250	75	10	0	20	5.10	6.28
24a	Newberg F.S.L. (Noble)	0-8"	60	10	50	150	4000	250	75	2	0	10	5.40	6.52
25a	Newberg S.L. (Kiger)	0-8"	50	10	50	*150	4000	250	75	10	0	20	5.32	6.48
2a	Chehalis L. (E. Coll. F.)	0-7"	60	20	75	150	4000	250	75	2	0	25	5.82	5.93
8a	Columbia F.S.L. (Jos. Co.)	0-8"	10	10	50	300	4000	250	75	2	0	10	5.62	6.45
1a	Willamette Si.C.L. (P.17)	0-7"	50	50	100	200	3000	250	75	2	0	10	5.47	5.47
4a	Willamette L. (Belton)	0-7"	50	35	50	200	3000	200	75	2	5	25	5.60	6.02
13a	Salem Si.L. (Jackson Co.)	0-8"	40	10	50	600	4000	250	75	2	0	25	5.65	5.55
3a	Sifton V.F.S.L. (Gilbert)	0-7"	100	35	40	150	3000	250	250	15	0	10	5.28	5.40
22a	Waldo C.L. (Gilbert)	0-8"	40	10	10	50	*500	30	500	5	5	25	5.00	5.12
12a	Carlton Si.C.L. (Yam. Co.)	0-8"	2	15	35	150	2500	250	250	5	5	25	5.55	5.73
7b	Melbourne L. (Douglas Co.)	1-7"	0	50	25	175	1000	250	75	2	5	25	6.05	6.40
9a	Milton Gr.S.L. (Um. Co.)	0-7"	100	10	50	600	4000	250	50	2	5	10	5.98	6.88
5a	Yakima F.L.S. (2 yrs. potatoes, 2 yrs. alf.)	0-8"	2	15	75	300	3000	250	75	2	0	25	6.05	7.18
6a	Yakima F.L.S. (2 yrs. potatoes, 6 yrs. alf.)	0-8"	2	20	75	600	3000	250	75	5	0	25	5.80	7.40
14a	Peat (Feaselman)	0-8"	100	50	25	50	*500	250	500	2	200	20	4.62	4.65
18a	Peat (Lake Labish)	0-8"	60	50	40	100	4000	250	75	2	0	20	5.82	6.10
21a	Muck and Peat (H. R. Co.)	0-8"	0	20	50	50	4000	250	100	2	15	25	5.87	6.45

* Values less than Quoted.

series of a different classification. The peats are grouped together without specific classification.

One of the interesting points illustrated by this table is the ratio of ferric to ferrous iron. The ferric iron is absent except in some of the more acid, or red hill soils. This coincides precisely with the findings by S. Kliman (1937), who seems to find that plants utilize only ferrous iron. This explains how most of the good soils can grow good crops yet contain little available ferric iron.

Among the recent alluvial soils of Oregon are the Newberg, Chehalis, and Columbia series. The Newberg and Chehalis series are closely related, the latter being on slightly higher ground, and less immature. Hydrolysis and leaching occur more intensely in the Newberg series which is the lower in available potassium. The Columbia series occurs mostly near the Columbia River, but the sample studied here was from Josephine County in Southern Oregon, and is much higher in available potassium than the other two series.

Old valley filling soils used include the Willamette, Salem, Sifton, and Waldo series. The Salem series is normally very similar to the Willamette series, except for the gravelly subsoil. Salem series, like the Columbia series also of Southern Oregon, is relatively high in available potassium. The two Willamette series samples show, again, that light soils hydrolyze more than heavy soils. The Sifton series, an excessively drained series high in organic matter, hydrolyzes moderately, and is low in available potassium. This latter factor is serious because of the very high nitrogen content. The Waldo series is eroded from the rolling hills of the Olympic series, a "red hill" soil, and deposited in the upland valleys. It is very low in available phosphorus, potassium, calcium, and magnesium; but has a fair supply of nitrogen. It is too high in aluminum due to its high acidity.

The residual soils represented are the Carlton and Melbourne series. The Carlton series is a hill soil colored similarly to the Willamette series, but it falls far short of the Willamette series in fertility. It is low in nitrogen, phosphorus, and potassium; medium in calcium, and probably too high in aluminum because of the acidity. The Melbourne sample, a reddish brown hill soil on a sedimentary parent material, from Douglas County has considerable ammonia nitrogen, but no nitrate nitrogen, which is very strange for a well drained soil with such a favorable pH. It is low in phosphorus, potassium, and calcium.

The Milton series in Umatilla County is found in the form of an alluvial fan at the mouth of a canyon. The surface is gently sloping. Old prune orchards are still thriving. According to tests by Morgan's system this soil needs only a small amount of phosphate to balance its nutrient ratio. It is very fertile.

The Yakima series is found in Klamath County on an old lake terrace. It is an excellent potato soil, but is low in nitrate. Here the sample highest in available potassium hydrolyzes most.

Parallel to the Oregon coast lies a series of small bodies of peat. The Feaselman peat is a member of this group from Clatsop County. The large amount of nitrate nitrogen produced in this test is surprising because of the low pH. It is low in phosphorus, potassium, and calcium, but high in aluminum and ferric iron. Due to its high acidity it is used chiefly for cranberries of which it produces in excellent quality.

The Lake Labish peat is found in Marion County. It is a nearly neutral peat; but moderately low in phosphorus, and very low in potassium. It is an excellent soil for vegetables and mint where fertilized. The "Muck and Peat" sample from Hood River County is found at an elevation of about 1800 feet surrounded by the Underwood series. While it is neutral it is low in nitrogen, medium low in phosphorus, and very low in potassium. Its area amounts to about five acres, and is being cropped to hay.

Table VII shows the correct fertilizer treatment for

TABLE VII

FERTILIZER NEEDS AS FOUND BY MORGAN'S SYSTEM FOR POTATOES

Series	Pounds per acre to be applied		
	N	P_2O_5	K_2O
Newberg	40	160	140
Chehalis	40	150	120
Columbia	100	160	80
Willamette	40	150	100
Sifton	20	160	120
Waldo	60	200	160
Carlton	120	170	120
Melbourne	80	180	110
Milton	20	160	20
Yakima	100	150	50
Peat (Feaselman)*	none	180	160
Peat (Lake Labish)	20	170	160
Muck and peat	100	160	160

* Hypothetical values

these soils according to Morgan's system using potatoes as the crop to be considered. For other crops, of course, these values must be changed accordingly.

The major part, by far, of the time spent for this study was spent using the Neubauer method for available potassium. This method, like all other methods for available nutrients, is purely empirical. Compared to the base exchange methods it is relatively poor with respect to reproducability because of the biological factors involved. Its accuracy can not be considered greater than one part in ten, although the analytical part of the method has been made accurate to more than one part per one hundred. In spite of its low reproducability this method is considered more reliable than base exchange methods because it takes into account the differences in the rates of availability of the so-called "non-replacable" potassium.

The complete set of profiles, by depths, covered in this study are given in Table VIII. The Neubauer values are expressed both in mg. per 100 grams of dry soil, and in pounds of K_2O per acre. The crop ratings are based on the limiting values already shown in Table IV.

Also shown in this table are the results of tests made by the Morgan method for purposes of comparison. Obviously this latter method, should and does give lower results in pounds per acre than the Neubauer method. The

TABLE VIII

A COMPARISON OF MORGAN AND NEUBAUER VALUES FOR AVAILABLE POTASH

No.	Sample		Neubauer Mg./100 gms.	Neubauer Lbs./acre	Neubauer Crop rating	Morgan Lbs./acre	Morgan Crop rating
1a	Willamette Si.C.L.	0 - 7"	28.7	573	grasses	240	grasses
b		7 -20"	37.7	752	potatoes	---	-------
2a	Chehalis loam	0 - 7"	45.7	918	potatoes	180	grains
b		7 -18"	48.9	979	potatoes	---	------
c		18 -40"	40.5	816	potatoes	---	------
3a	Sifton Gr. sooty	0 - 7"	32.9	661	legumes	180	grains
b	V.F.S.L.	20 -36"	10.3	209	(deficient)	---	------
4a	Willamette loam	0 - 7"	23.1	461	grains	240	grasses
b		7 -18"	27.3	549	grains	---	-------
c		18 -36"	29.7	596	grasses	---	-------
5a	Yakima F.L.S.	0 - 8"	23.1	561	grains	360	legumes
b		8 -22"	39.1	781	potatoes	---	-------
c		22 -36"	41.9	837	potatoes	---	-------
6a	Yakima F.L.S.	0 - 8"	33.9	677	legumes	725	potatoes
b		8 -22"	46.1	922	potatoes	---	--------
c		22 -32"	43.3	865	potatoes	---	--------

TABLE VIII (continued)

No.	Sample		Neubauer Mg./100 gms.	Lbs./acre	Crop rating	Morgan Lbs./acre	Crop rating
7a	Melbourne loam	0 - 1"	40.5	808	potatoes	---	-----
b		1 - 7"	35.3	709	legumes	210	grain
c		7 -12"	25.9	515	grains	---	-----
d		12 -24"	26.4	528	grains	---	-----
e		28 -30"	15.1	300	(deficient)	---	-----
8a	Columbia F.S.L.	0 - 8"	39.5	791	potatoes	260	grasses
b		8 -18"	43.3	871	potatoes	---	-------
c		18 -36"	34.8	695	legumes	---	-------
9a	Milton Gr.S.L.	0 - 7"	52.7	1055	grapes	720	potatoes
b		7 -24"	41.9	842	potatoes	---	--------
10a	Nes Perce	0 - 7"	45.2	900	potatoes	---	--------
b		8 -18"	51.8	1033	grapes	---	--------
11a	Melbourne	0 - 7"	11.3	223	(deficient)	---	--------
b	(Lincoln Co.)	8 -14"	8.9	177	(deficient)	---	--------
c		15 -30"	10.3	204	(deficient)	---	--------
d		30 -48"	15.5	312	(deficient)	---	--------
e		49 -54"	15.1	300	(deficient)	---	--------
12a	Carlton Si.C.L.	0 - 8"	25.4	507	grains	160	grains
b		8 -15"	13.2	265	(deficient)	---	------
c		15 -26"	11.2	231	(deficient)	---	------
d		28 -34"	14.1	286	(deficient)	---	------
e		36 -48"	22.1	441	grains	---	------

TABLE VIII (continued)

No.	Sample		Mg./100 gms.	Neubauer Lbs./acre	Crop rating	Morgan Lbs./acre	Crop rating
13a	Salem Si. L.	0 - 8"	48.5	970	potatoes	725	potatoes
b		8 -18"	40.0	800	potatoes	---	--------
14a	Peat (Feaselman)	0 - 8"	15.7	38*	(deficient)	none	(deficient)
b		8 -14"	13.6	20*	(deficient)	----	-----------
15a	Ditterline	top	25.9	523	grains	---	-------
b		subsoil	32.5	648	grasses	---	-------
16a	Powell Si. L.	0 - 6"	33.9	677	legumes	---	-------
b		6 -12"	25.4	513	grains	---	-------
c		12 -18"	15.1	305	(deficient)	---	-------
d		18 -24"	15.1	298	(deficient)	---	-------
e		24 -36"	12.7	258	(deficient)	---	-------
17a	Newberg S.L.	0 - 7"	19.3	390	(deficient)	100	(deficient)
b		7 -18"	32.9	656	legumes	---	-----------
c		18 -20"	34.3	692	legumes	---	-----------
18a	Peat (Lake Labish)	0 - 7"	5.2	37*	(deficient)	50	(deficient)
b		7 -19"	-3.8	-25*	(deficient)	--	-----------
c		19 -31"	7.5	45*	(deficient)	--	-----------
19a	Tumalo S.L.	0 -12"	27.3	546	grains	---	-------
b		12 -24"	23.5	470	grains	---	-------

TABLE VIII (continued)

No.	Sample		Mg./100 gms.	Neubauer Lbs./acre	Crop rating	Lbs./acre	Crop rating
20a	Deschutes S.L.	0 -12"	29.7	589	grasses	---	-------
b		12 -24"	17.6	350	(deficient)	---	-------
21a	Muck and peat	0 - 8"	-3.8	-22*	(deficient)	50	(deficient)
b	(Hood River Co.)	8 -15"	0.5	8*	(deficient)	--	-----------
c		15 -18"	4.7	58*	(deficient)	--	-----------
22a	Waldo C.L.	0 - 8"	1.9	38	(deficient)	50	(deficient)
23a	Chehalis loam (Wyss)	0 -12"	21.6	432	grains	---	-------
24a	Newberg F.S.L.	0 - 8"	23.5	470	grains	180	grains
b	(Noble)	8 -18"	25.4	508	grains	---	------
c		18 -36"	14.6	292	(deficient)	---	------
25a	Newberg S.L. (Kiger)	0 - 8"	19.8	396	(deficient)	120	(deficient)

* Corrected for specific gravity

only possibility of comparing these two methods is by the use of their respective crop ratings which are purely arbitrary for both methods. For the Morgan method these ratings are as follows:

Pounds of potassium per acre	Crop rating
Below 150	(deficient)
150 - 199	grains
200 - 299	grasses
300 - 499	legumes
500 and higher	potatoes

These two widely different methods agree fairly well with surface soils. However, with the Chehalis, Sifton, and Columbia series the Morgan method gives lower results, and with the Yakima series it gives somewhat higher results.

SPECIAL SOIL STUDIES

Obviously, for a study of this kind, greenhouse and field trials can not be made as extensively as the more rapid laboratory tests. Consequently only a few of the samples shown in Tables VI, VII, and VIII have had such tests made upon them. Most of the field trials have been conducted by Dr. W. L. Powers, although the writer has assisted with all of the trials herein mentioned.

NEWBERG SERIES. During the season of 1937 a fertilizer trial was established on Newberg sandy loam on Pflageman's property northeast of Albany, Oregon. One acre of the field was laid off into ten plots of one tenth acre each and fertilized. The yield data are shown in Table IX.

In plot two nitrogen or phosphorus is causing an increase. Plot five shows that phosphorus and potassium can do nearly as well, while plot three indicates a decided need for phosphorus. Apparently the best rate is that used on plot six, namely, 30 pounds of N, 90 pounds of P_2O_5, and 60 pounds of K_2O per acre. The yield dropped when potassium was omitted.

Both the Morgan and Neubauer method show a deficiency of potassium in the top seven inches of the Newberg soil. In Table VIII, as may be seen, from seven inches downward there is enough potassium for legumes, which is only slightly less than enough for potatoes according to the Neubauer values. There is definitely no potassium deficiency according to the field trials. Thus one can readily see how the practice of studying surface soil only may lead to badly erroneous conclusions. The Morgan data were obtained in this study on surface samples for comparative purposes only, hence the absence of subsoil determinations by this method. After fertilizing as on plot six the mol ratios are:

$$\begin{array}{ccccc} N & : & P & : & K \\ 100 & : & 49 & : & 48 \end{array}$$

Evidently a mol ratio of 2 : 1 : 1 is nearly correct for this soil.

TABLE IX

A FERTILIZER TRIAL WITH POTATOES ON NEWBERG SANDY LOAM

Plot	Treatment	Bu. per acre	Increase %
1	check	237	0.0
2	30 lbs. N, 90 lbs. P_2O_5	262	10.5
3	30 lbs. N, 60 lbs. K_2O	242	2.1
4	check	237	0.0
5	90 lbs. P_2O_5, 60 lbs. K_2O	251	8.2
6	30 lbs. N, 90 lbs. P_2O_5, 60 lbs. K_2O	267	17.1
7	check	223	0.0
8	30 lbs. N, 90 lbs. P_2O_5, 30 lbs. K_2O	241	9.6
9	30 lbs. N, 90 lbs. P_2O_5, 90 lbs. K_2O	236	8.3
10	check	215	0.0

TABLE X

A SUMMARY OF A TEN YEAR FERTILIZER STUDY

ON CHEHALIS LOAM WITH POTATOES

Plot	Treatment	Ave. bu. per acre
4	200 lbs. superphosphate	230.75
5	check	234.64
6	100 lbs. each of $NaNO_3$, treble, and KCl	251.68
7	100 lbs. each of treble and KCl	230.17
8	100 lbs. each of $NaNO_3$ and KCl	268.58
9	check	249.07
10	250 lbs. gypsum	280.16
12	50 lbs. sulfur	258.67
13	check	266.65
15	100 lbs. K_2SO_4	253.43

CHEHALIS SERIES. Chehalis is the main series of soils found on the East College Farm. Most of the fertility work done on this farm was established before a suitable system of fertilizer ratios had been developed here. However, potatoes were included in the crop system of the fertility plots and the yield data for this crop are shown in Table X.

From this table one can see that plots fertilized with complete were no better than with omission of phosphorus, which apparently was not very important for potatoes. Plots four, seven, twelve, and fifteen each show that phosphorus, sulfur, and potassium, alone, or in combination with each other are not sufficient. Plot eight indicates that nitrogen and potassium are the elements especially required for potatoes on this soil.

According to the Neubauer values this soil is amply supplied with potassium, yet both the field data and the Morgan test data show it to be low. The field test indicates a need for nitrogen, and the Morgan test indicates no nitrogen need. Again, the field test indicates no need for phosphorus, while the Morgan test indicates a need for that element with potatoes, which have a high phosphorus requirement. The probable answer to these apparent contradictions lies in plot ten which was treated with 250 pounds of gypsum. The "Law of the Minimum" applies. The small amounts of sulfur applied in plots four and fifteen may be inadequate when coupled with the injurious effect of unbalanced fertility caused by the use of a single major nutrient.

POWELL SERIES. Only Neubauer determinations for available potassium were made in the laboratory on the one profile sample of this series. The top foot contained some available potassium, while the next two feet downward were deficient. According to the Neubauer tests the entire profile was too low in available potassium to meet the requirements for potatoes.

The field trial was crowded between a border and an area already fertilized, thus the results suffer from the lack of two checks. In spite of this difficulty Table XI distinctly shows a need for a heavy application of potassium. Apparently the two methods are entirely in agreement on this series. The soil evidently should be fertilized with about 30 pounds N, 90 pounds P_2O_5, and 90 pounds K_2O per acre.

YAKIMA SERIES. These soils as mapped in the Klamath Basin are remarkably adapted to potatoes for location, climate, and texture. According to the Morgan tests, however, they are low in available phosphorus and nitrogen. Compared to the field trial data in Table XII this is true. The Neubauer tests show sufficient potassium in all but the top eight inches.

TABLE XI

A FERTILIZER TRIAL WITH POTATOES ON POWELL SILT LOAM

Plot	Treatment	Bu. per acre	Increase %
1	90 lbs. P_2O_5, 60 lbs. K_2O	484	-----
2	30 lbs. N, 60 lbs. K_2O	516	-----
3	check	548	0.0
4	30 lbs. N, 90 lbs. P_2O_5	376	-38.0
5	30 lbs. N, 90 lbs. P_2O_5, 60 lbs. K_2O	436	-5.6
6	check	420	0.0
7	30 lbs. N, 90 lbs. P_2O_5, 30 lbs. K_2O	428	-----
8	30 lbs. N, 90 lbs. P_2O_5, 90 lbs. K_2O	470	-----*

* probably correct ratio

TABLE XII

A FERTILIZER TRIAL WITH POTATOES ON YAKIMA FINE SANDY LOAM

Plot	Treatment	Bu. per acre	Increase %
1	check	225	0.0
2	30 lbs. N, 90 lbs. P_2O_5	273	8.0
3	30 lbs. N, 60 lbs. K_2O	281	1.1
4	check	297	0.0
5	90 lbs. P_2O_5, 60 lbs. K_2O	300	-4.5
6	30 lbs. N, 90 lbs. P_2O_5, 60 lbs. K_2O	306	-7.6
7	check	349	0.0
8	30 lbs. N, 90 lbs. P_2O_5, 30 lbs. K_2O	361	0.0
9	30 lbs. N, 90 lbs. P_2O_5, 90 lbs. K_2O	360	-3.5
10	check	384	0.0

The importance of balanced nutrient ratios is shown clearly with this soil. An addition of potassium in any amount causes a decrease in yield. Had enough nitrogen and phosphorus been added in the correct ratio this might not have been true. Under the conditions of the trial as made, however, plot two is the only successful one. After fertilizing this plot the mol ratios were:

N	:	P	:	K
100	:	113	:	432

This is not the ratio that should be expected. Evidently these plots needed 240 to 300 pounds of nitrogen, and about 360 pounds of P_2O_5 per acre to balance the ratio.

LAKE LABISH PEAT. This soil is nearly neutral, and has excellent physical properties. Chemically it is low in both phosphorus and potassium, especially the latter. Both chemical methods agree upon its being deficient in potassium.

Table XIII shows the field trial data with beets. There seems to be little doubt that plot nine with a high rate of potassium has much the best treatment of the set of plots. Plot three indicates a small need for nitrogen. The photographs on Plates II and III show clearly the relative growth and yield of beets on these plots.

Plate IV shows a bean leaf from an unfertilized row from a field adjacent to the beet plots. The coloration is typically a potash deficiency symptom. Plate V shows

TABLE XIII

A FERTILIZER TRIAL WITH DETROIT DARK RED BEETS

ON LAKE LABISH PEAT

Plot	Treatment	Ton beets per acre 2 yr. ave.	Increase %
1	check	0.66	0
2	30 lbs. N, 90 lbs. P_2O_5	1.97	101
3	30 lbs. N, 60 lbs. K_2O	3.03	140
4	check	1.56	0
5	90 lbs. P_2O_5, 60 lbs. K_2O -N	2.40	56
6	30 lbs. N, 90 lbs. P_2O_5, 60 lbs. K_2O	2.96	95
7	check	1.50	0
8	30 lbs. N, 90 lbs. P_2O_5, 30 lbs. K_2O	3.08	108
9	30 lbs. N, 90 lbs. P_2O_5, 90 lbs. K_2O	4.23	186
10	check	1.46	0

Lake Labish beets showing the relative growth and yield of several plots

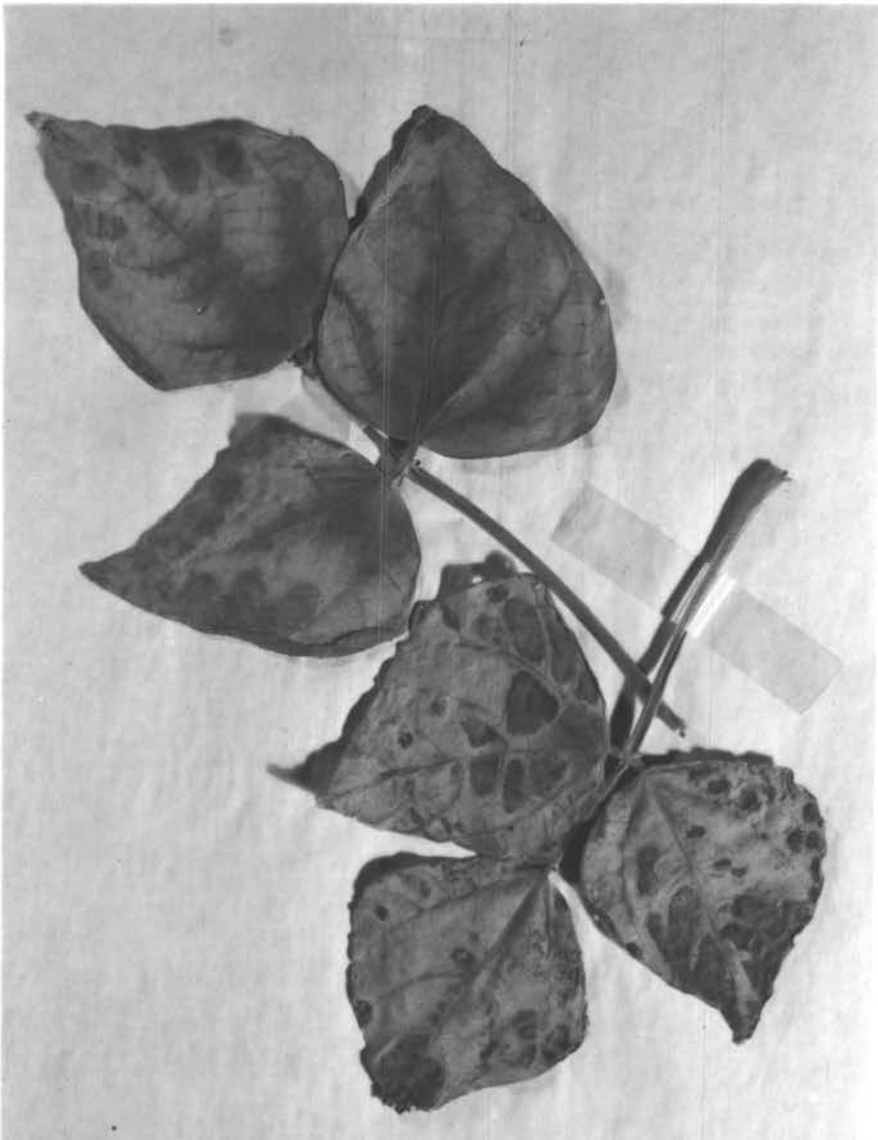
Plate II

Beets growing on Lake Labish

NP - 30 lbs. N, 90 lbs. P_2O_5 per acre

NK - 30 lbs. N, 60 lbs. K_2O per acre

Plate III

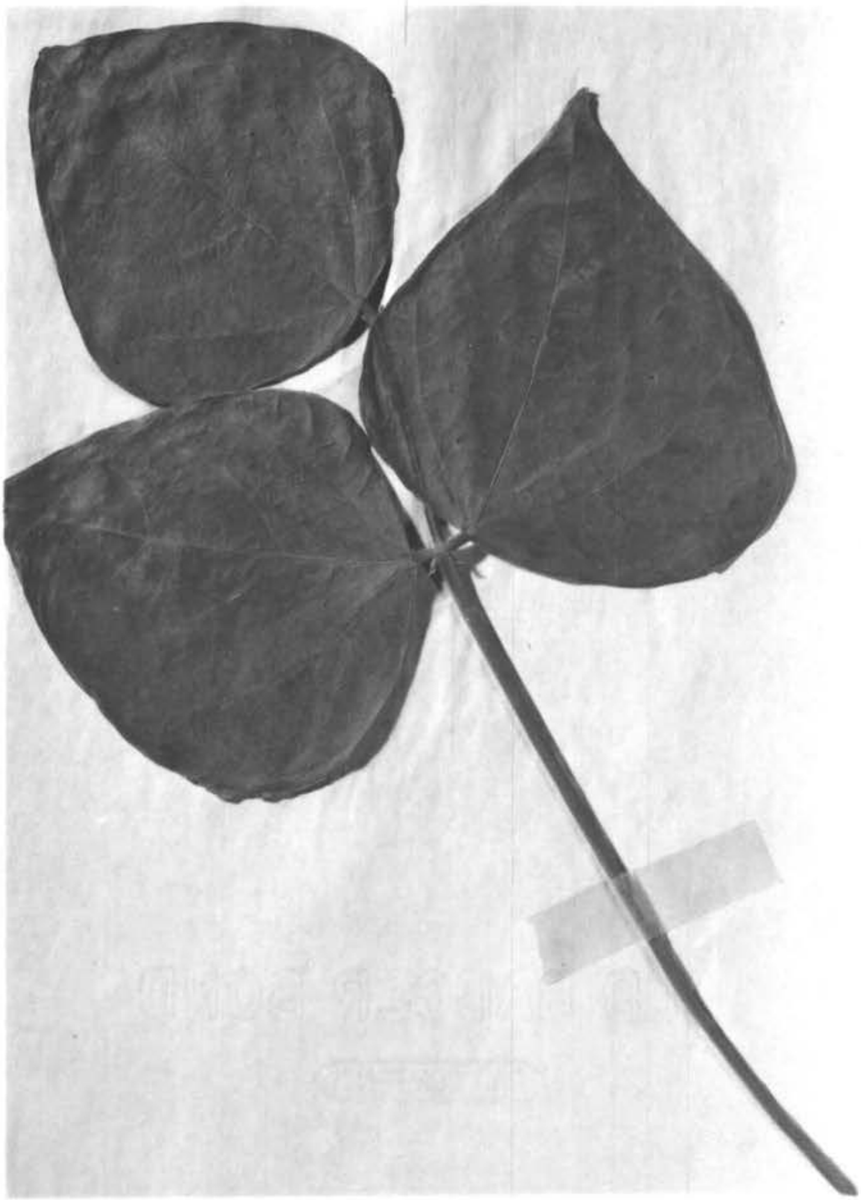


Bean leaves grown on Lake Labish

Unfertilized

Note potash deficiency symptoms

Plate IV



Bean leaf grown on Lake Labish
Fertilized with 3-10-10
No potash deficiency symptoms

Plate V

how the beans respond in a row treated with a 3-10-10 fertilizer. The rows were 42 inches apart, and 560 feet long. The fertilizer was applied at the rate of 50 pounds per row.

Both the Morgan and Neubauer tests show this soil to be very deficient in potassium. The former test also indicates a need for phosphorus, but only a slight need for nitrogen. A high potassium complete fertilizer gave the maximum yield in the field trial.

In an attempt to study the physiological influences of the fertilizer ratios a laboratory study was made by analyzing samples from the field plots for sugar, as beets of all varieties are good producers of that substance. The results are shown in Table XIV.

As shown before, the best yield increase came from the high potash plot with the minus phosphorus plot second. The high potash plot likewise produced the lowest leaf to root ratio, the "complete" was second, and the minus nitrogen plot third. The minus nitrogen plot produced the highest per cent sugar, the high potash plot second, and all other fertilized plots were below the checks. Plot three, however, produced the most surprising results by showing how severely an unbalanced nutrient ratio with respect to a low phosphorus value could upset the physiological functions of a plant. The loss in sugar production was tremendous.

In an effort to clarify the field trial results a

TABLE XIV

THE INFLUENCE OF FERTILIZER ON THE

PHYSIOLOGY OF BEETS (1937)

Plot	Treatment	Wt. roots per acre	Ratio tops/roots	Sugar in roots % dry wt.
1	check	515	4.84	39.6
2	N + P	1390	2.24	39.5
3	N + K	4390	1.39	1.8
4	check	1230	2.66	43.7
5	P + K	3650	1.19	49.0
6	"complete"	4870	1.16	33.1
7	check	2415	1.69	44.7
8	low potash	4420	1.72	30.1
9	high potash	7420	1.09	40.5
10	check	1895	3.23	37.2

TABLE XV

A GREENHOUSE STUDY WITH BEETS ON LAKE LABISH PEAT

Lbs. per acre $N-P_2O_5-K_2O$	Ave. wt. per jar whole plants gm.	Ave. wt. per jar root gm.
0- 0- 0	61	31
30- 90- 0	49	15
30- 0- 60	77	45
0- 90- 60	84	48
30- 90- 15	62	35
30- 90- 30	69	35
30- 90- 60	67	35
30- 90- 90	79	47
30- 90-120	99	66
30-135- 80	80	44
45-135- 90	76	46

series of greenhouse tests were made using this peat. The jars each contained 3.82 kilograms of dry peat, and were fertilized in duplicate as shown in Table XV. Both the minus nitrogen and minus phosphorus sets of jars showed an increase in yield. The minus potassium set showed a distinct loss in yield. Of the groups of tri-nutrient jars, with potassium rates, no marked increase in yield appeared until 90 pounds per acre of potash had been applied. A 120 pound application made a much greater increase indicating that even this rate of application was too low. Increases in the ratios of either nitrogen or phosphorus seemed to be immaterial.

Plate VI shows the beets growing in several jars with different treatments. The leaves in the check and low potassium jars are smaller, more wrinkled, and spotted in color. Three representative plants from each set of jars were photographed, after harvesting, in two groups as shown in Plate VII. The $N_2+P_2+K_4$ set receiving 30 pounds of nitrogen, 90 pounds of P_2O_5, and 120 pounds of K_2O per acre is the most perfect set of the group. The labels may be translated into pounds per acre as follows:

$$N_2 = 30\ N$$

$$P_2 = 90\ P_2O_5$$

$$K_2 = 60\ K_2O$$

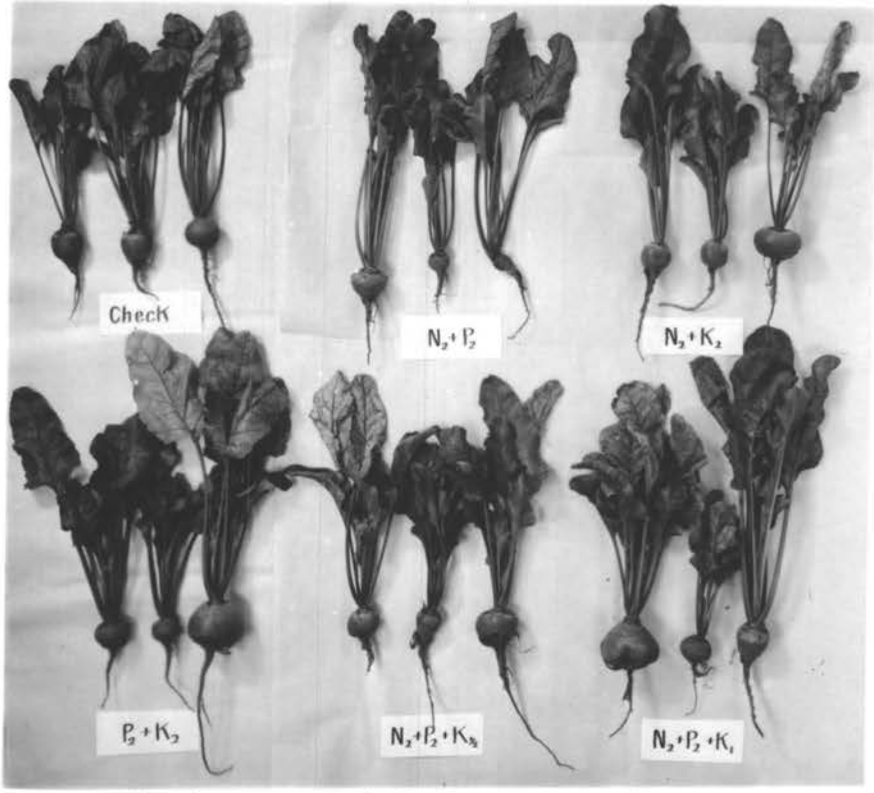
Plate VIII is a close-up view of plants from several jars.

Beets growing on Lake Labish peat

Jar	$N - P_2O_5 - K_2O$*
Check	0 - 0 - 0
$N_2-P_2-K_{1/2}$	30 - 90 - 15
$N_2-P_2-K_4$	30 - 90 - 120
$N_2-P_3-K_3$	30 - 135 - 90

* Lbs. per acre

Plate VI



Beets harvested from greenhouse
experiment

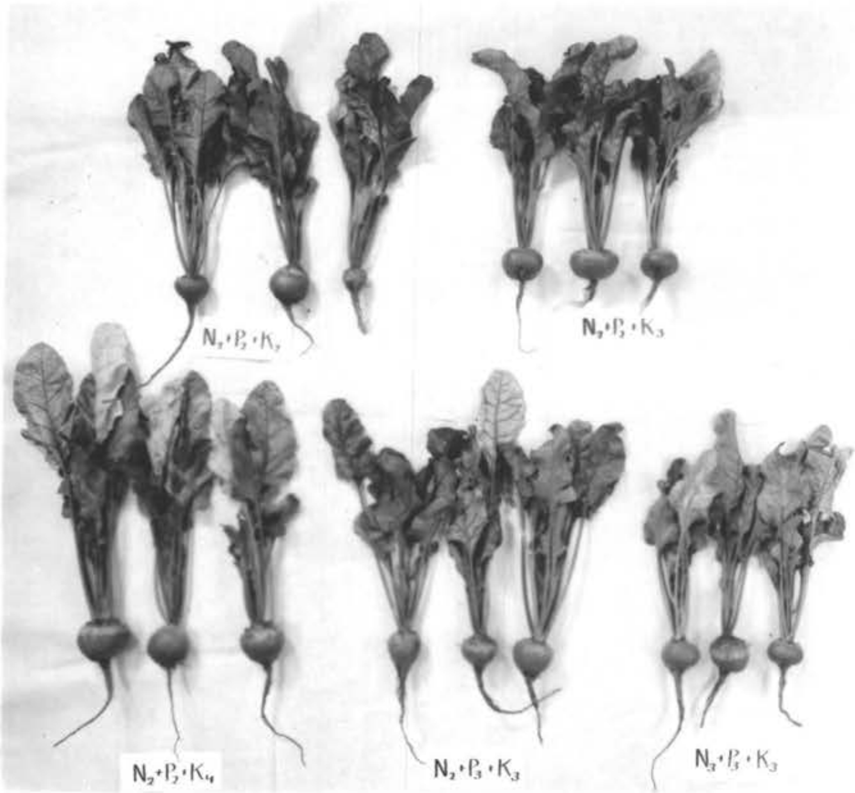
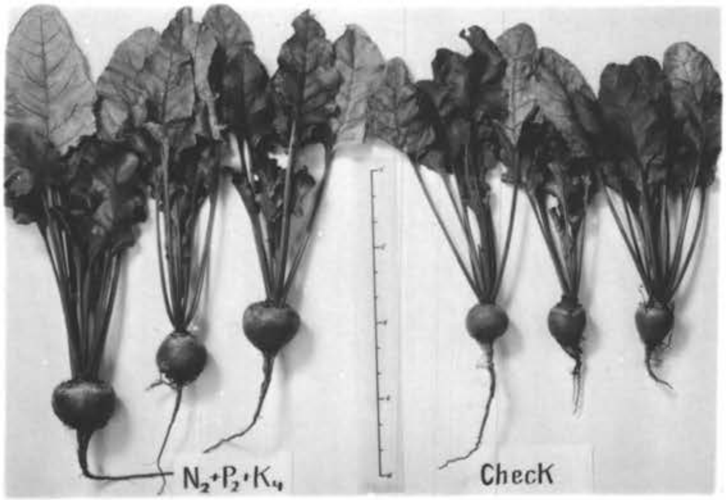
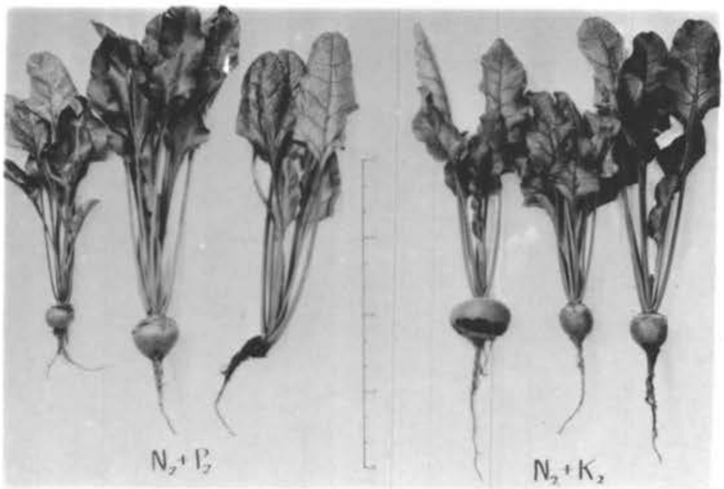


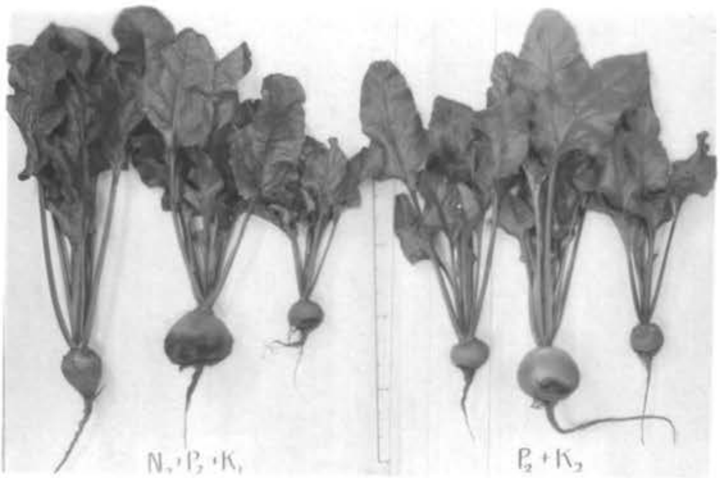
Plate VII



30 - 90 - 120 0 - 0 - 0



30 - 90 - 0 30 - 0 - 60



30 - 90 - 30 0 - 90 - 60

A detailed view of greenhouse beets
Plate VIII

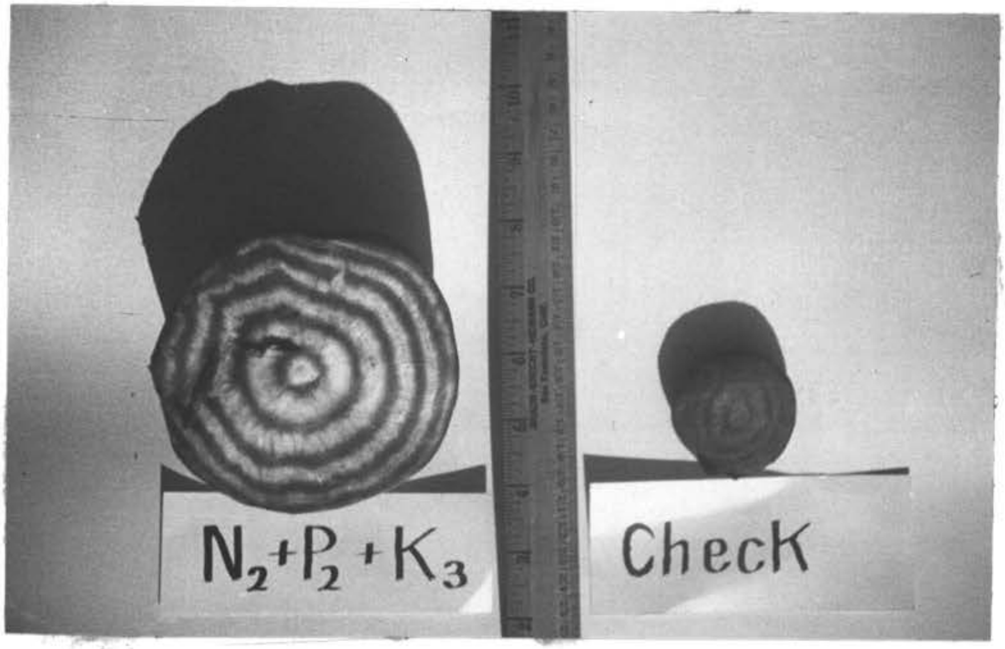
The plants receiving a high rate of potassium grow faster, and apparently mature earlier. If left too long white rings develop and the beets become woody and less edible. For table use these beets should be harvested earlier than unfertilized beets. Plate IX shows this condition clearly.

Following the beets another experiment using Rosen rye was set up as shown in Table XVI. This plant has a low potassium requirement and the yield data are not outstanding although the high rate of potassium again gave the best yield. Some of the jars are shown in Plates X and XI.

After removing the rye the jars were replanted to White Icicle radishes without retreatment. The yield and analytical data are shown in Table XVII.

Apparently the 30-90-180 rate is about correct for the radishes. The greenhouse rate of 30-135-90 was only slightly below the 30-90-180 rate for yield, but it probably would have been much higher if the K_2O had been raised to 180. The photographs on Plates XII, XIII, and XIV show quite well the comparative sizes of the roots.

After the radishes were harvested the soils were analyzed by the Morgan methods. The data are shown in Table XVIII. In the jars where poor growth occurred there seemed to be a tendency for nitrates to accumulate. The phosphorus left depended on the amount applied, and somewhat on



Cross-section of beets from greenhouse

Note white rings in the high K beet

Plate IX

TABLE XVI

A GREENHOUSE STUDY WITH ROSEN RYE ON LAKE LABISH PEAT

Lbs. per acre $N-P_2O_5-K_2O$	Rye fresh wt. gms./jar	K removed gm./jar	Dry wt. %
0- 0- 0	64.2	0.101	0.63
30- 90- 0	68.3	0.102	0.63
30- 0- 60	74.8	0.291	1.40
0- 90- 60	68.8	0.340	1.90
30- 90- 30	74.0	0.184	0.82
30- 90- 60	76.6	0.269	1.27
30- 90- 90	72.7	0.355	1.89
30- 90-120	74.8	0.442	2.13
30- 90-180	80.4	0.591	2.46
30-135- 90	65.2	0.341	1.76
45-135- 90	67.7	0.297	1.43

Note: All jars received in P.P.M. :
B - Zn - Sn - Mn - Cu - Mg - S
2.7-3.6 -8.3 -4.6 -2.0 - 31 - 46

TABLE XVII

DATA ON RADISHES GROWN IN JARS OF LAKE LABISH PEAT

Lbs. per acre $N-P_2O_5-K_2O$	Radish tops gms./jar	roots gms./jar	Ratio tops/roots	K in tops %	roots %	K lost mg/jar
0- 0- 0	44	2	17.8	0.040	0.043	18.7
30- 90- 0	29	2	19.0	.035	.069	11.1
30- 0- 60	61	17	3.6	.050	.073	42.8
0- 90- 60	60	12	5.0	.044	.118	40.7
30- 90- 30	58	8	7.3	.038	.070	27.6
30- 90- 60	63	17	3.6	.043	.083	41.4
30- 90- 90	74	11	6.7	.061	.118	58.7
30- 90-120	73	31	3.5	.070	.154	84.0
30- 90-180	69	37	1.9	.108	.167	136.5
30-135- 90	73	32	2.3	.049	.099	67.6
45-135- 90	61	28	2.2	.056	.100	66.2

Note: Minor elements applied as in Table XVI.

0 - 0 - 0

30 - 90 - 0

Rye in greenhouse on Lake Labish peat

All jars were planted with 100 seeds

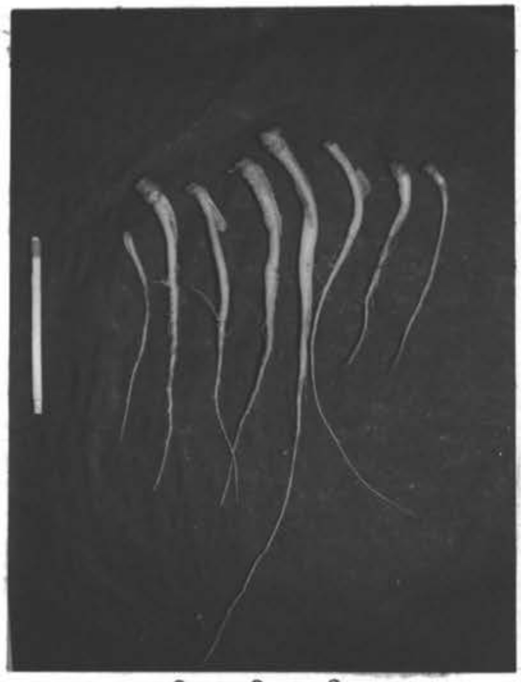
Plate X

30 - 90 - 90

Top - Continued from Plate X

Bottom - A general view of the rye experiment

Plate XI



0 - 0 - 0

30 - 90 - 0

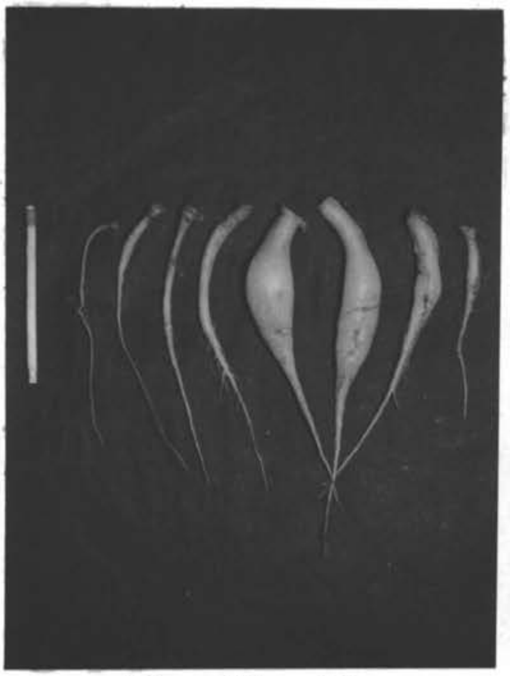
30 - 0 - 60

0 - 90 - 60

Radishes from greenhouse experiment with

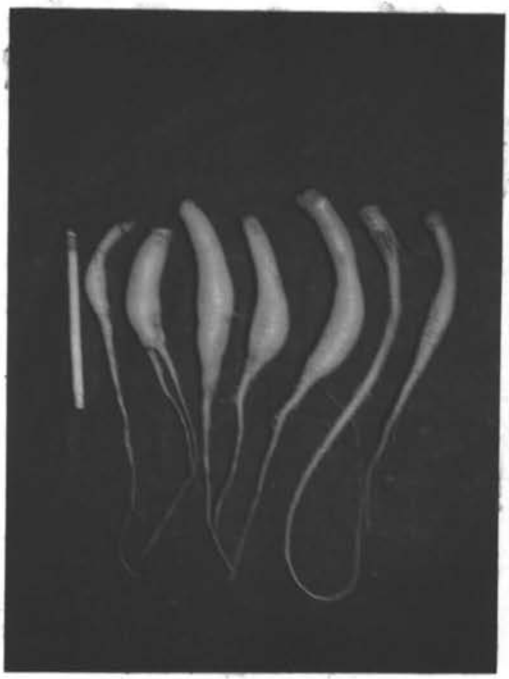
Lake Labish peat

Plate XII

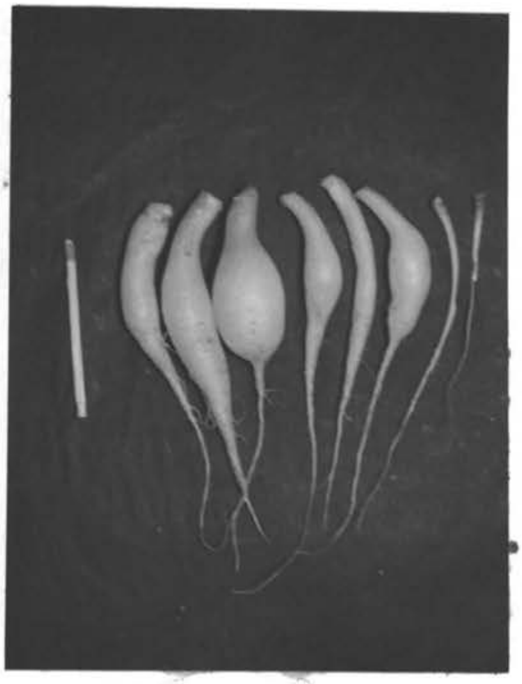


30 - 90 - 30

30 - 90 - 60



30 - 90 - 90

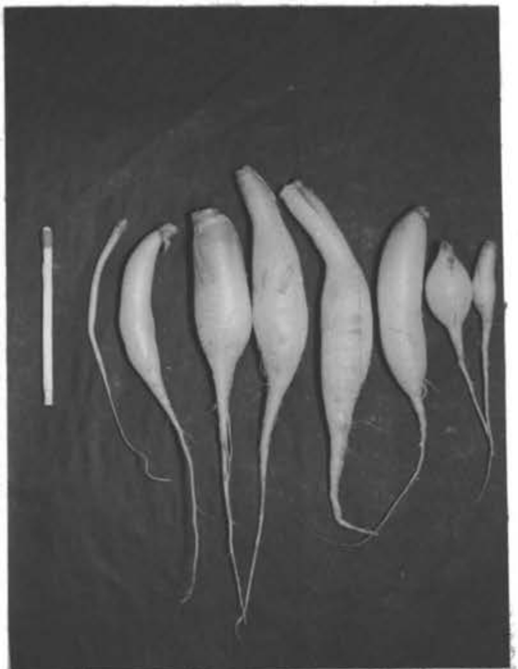


30 - 90 - 120

Plate XIII

30 - 90 - 180

30 - 135 - 90



45 - 135 - 90

Plate XIV

TABLE XVIII

ANALYSES OF GREENHOUSE JARS OF LAKE LABISH PEAT AFTER CROPPING WITH RYE AND RADISHES

Initial Treatment $N - P_2O_5 - K_2O$	NO_3 N	NH_3 N	P	K	Ca	Mg	Al	Mn	Fe^{+3}	Fe^{+2}	pH 1:5 dilution
	Pounds of Nutrient Per Acre										
0 - 0 - 0	50	trace	25	0	4000	250	75	2	0	25	6.17
30 - 90 - 0	60	"	75	0	4000	250	50	2	0	25	6.18
30 - 0 - 60	25	"	25	0	4000	250	50	2	0	25	6.18
0 - 90 - 60	15	5	100	0	4000	250	50	2	0	25	6.18
30 - 90 - 30	30	trace	125	0	4000	250	50	2	5	25	6.18
30 - 90 - 60	30	"	50	0	4000	250	75	2	0	25	6.22
30 - 90 - 90	20	5	75	0	4000	250	75	2	5	25	6.27
30 - 90 - 120	30	trace	100	0	3500	250	75	2	5	25	6.19
30 - 90 - 180	10	5	150	0	4000	250	75	2	5	25	6.38
30 - 135 - 90	35	5	150	0	3500	175	50	2	0	25	6.27
45 - 135 - 90	10	trace	150	0	4000	250	75	2	5	25	6.28

fertilizer ratios. In all cases the potassium test showed a blank. This indicates that all of that nutrient which had been applied had been utilized with the soil again becoming deficient.

Table XIX shows an expected decrease in recovery as the rate of potassium application increases. With both rye and radishes the 30-90-90 jars showed a decreased yield yet the potassium consumption and the efficiency in assimilation was markedly increased. An increase in nitrogen causes a decrease in the per cent of potassium recovered, while an increase in phosphorus causes an increase in the per cent potassium recovered.

The mol ratios in the original peat are as follows:

N	:	P	:	K
100	:	16	:	10

After receiving a 30-90-180 treatment the mol ratio is:

N	:	P	:	K
100	:	25	:	49

If treated as recommended by the Morgan system the mol ratio becomes:

N	:	P	:	K
100	:	35	:	46

Assuming a 75 per cent loss of phosphorus by fixation, this latter ratio, approaching a 2 : 1 : 1 ratio, is probably more nearly correct.

FEASELMAN PEAT. This body of peat lies east of Camp Clatsop, Clatsop County, Oregon, parallel to the banks,

TABLE XIX

RECOVERY OF POTASSIUM FROM LAKE LABISH PEAT BY RYE AND RADISHES

Lbs. per acre $N-P_2O_5-K_2O$	Total K recovered gm./jar	K added gm./jar	K recovered* %
0- 0- 0	0.120	0.000	100
30- 90- 0	0.113	0.000	94
30- 0- 60	0.334	0.280	84
0- 90- 60	0.381	0.280	95
30- 90- 30	0.212	0.140	82
30- 90- 60	0.310	0.280	78
30- 90- 90	0.414	0.350	88
30- 90-120	0.526	0.560	77
30- 90-180	0.727	0.840	76
30-135- 90	0.409	0.352	87
45-135- 90	0.363	0.352	77

* Computed as follows: total K recovered, multiplied by 100, divided by 0.120 plus K added.

TABLE XX

DATA ON CRANBERRIES FROM FEASELMAN PEAT

Lbs. per acre $N-P_2O_5-K_2O$	Spoilage* in 1 Mo. %	Berries* per oz. No.	Sap pH	K dry wt. %
0- 0- 0	6.3	30.7	2.68	0.303
30- 90- 0	7.8	27.6	2.53	0.288
30- 0- 60	11.6	30.7	2.53	0.335
0- 0- 0	11.8	32.0	2.58	0.305
0- 90- 60	8.0	27.9	2.57	0.348
30- 90- 60	10.4	28.5	2.60	0.323
0- 0- 0	7.0	26.1	2.52	0.451
30- 90- 30	7.0	27.2	2.54	0.386
30- 90- 90	5.4	25.1	2.60	0.414
0- 0- 0	7.0	23.6	----	-----

* Two year average.

below the head of tide water, of the meandering Skipponon River. It is essentially a sedge peat, although it contains branches and leaves of brush, and pieces of trees from small branches to trunks two feet in diameter. The portion studied is a cranberry bog owned, at this time, by A. H. Feaselman. Underneath the plots the peat is about nine feet deep lying on a somewhat compact sandy formation. Although the bog is protected from high tides by a dike the water in the bog itself varies two to three feet with the tides. At high tide this level approaches to within six to twelve inches of the bog surface.

A field trial treated as shown in Table XX was set up on this peat in the spring of 1937, and repeated again in 1938. The crop of each season was injured by frost to such an extent that yield data could not be obtained.

In the laboratory the berries were sized, examined for spoilage, and analyzed for potassium. A pH study was also made on expressed sap. No outstanding variations were to be noted except in the case of the berries treated with 0-90-60. In this case the berries were larger, had less spoilage, and had a higher potassium content.

The chemical methods of analyses used show the soil to be extremely deficient in potassium, very high in nitrogen, and low in available phosphorus. This explains why the 0-90-60 treatment showed a fair response. As data are lacking with regards to the nutrient requirements of cranberries it is impossible to predict a required fertilizer treatment. If this plant has a low requirement for both phosphorus and potassium its rate probably would be somewhat similar to 0-90-60.

At high tide the river adjacent to the bog contains 153 parts per million of sodium and 8.63 parts per million of potassium. At low tide these figures are changed to 21 and 3.6 respectively.

Mol ratio at high tide	Na : K	17.7 : 1
Mol ratio at low tide	Na : K	5.9 : 1

The peat contains 5.10 M.E. of water soluble sodium per 100 grams of dry soil, and only 0.32 M.E. of potassium. This is a mol ratio for Na to K of 16 to 1 which is similar to that of the river at high tide.

The total sodium content of this peat is 5.34 M.E. per 100 grams of dry soil, while the total potassium content is 1.89 M.E. per 100 grams. This gives a mol ratio of 2.8 to 1. It contains 1.73 M.E. of exchangeable sodium and 0.70 M.E. of exchangeable potassium per 100 grams of dry soil; a mol ratio of 2.5 to 1. It is thus evident that the soil solution is essentially river water at high tide. The exchangeable nutrients are closely related to the total.

Although the soil has a base exchange capacity of 76.2 M.E. per 100 grams of dry soil, calcium only accounts for 8.84 M.E., and magnesium 8.24 M.E. This is a mol ratio for

Ca to Mg of 1.1 to 1.0, and Ca to K of 6.3 to 1.

With a pH of 4.67, being highly unsaturated, having too little calcium and potassium, and having, perhaps, adverse Ca : Mg and Na : K ratios, there is little chance of keeping any large quantity of a soluble nutrient such as potassium in this soil. The conditions on the bog are comparable to laboratory conditions where a soil may be leached with a sodium salt to replace other bases. Several light applications of fertilizer during a growing season might be better than one relatively heavy application in the spring.

SUMMARY

A brief review of the literature concerning the potassium in relation to fertility of soils is presented. Summaries from the literature concerning the relative availability of potassium from minerals, nutrient ratios, and "limiting" Neubauer values are summarized in table form.

The common methods of studying soil fertility are discussed. The methods used in this study are described, and the necessary changes have been noted.

Many Oregon soils have been studied with respect to nitrogen and phosphorus availability, in their relationship to the availability of potassium. The optimum mol ratios for available nitrogen, phosphorus, and potassium in the soil has been found to be about 2 : 1 : 1 respectively. The weight ratio for N : P_2O_5 : K_2O would be 1 : 2.5 : 1.7, or roughly 30-90-60.

Organic and acid soils, along with Western Oregon sandy soils, have been found likely to be deficient in available potassium.

BIBLIOGRAPHY

Arrhenius, O. Experiments concerning the importance of the potash and phosphoric acid nutrition to cultivated plants. Medd. Centralanstalt. førsøksvasendel. jordbruks. No. 41, 12 pp. 1927.

Bear, F. E. Theory and practice in the use of fertilizers. John Wiley and Sons, Inc. New York City, New York. p. 273, 1929. Second Ed. p. 271, 1938.

Becker-Dillingen, J. The cultivation, plant-food requirements and fertilizing of rhubarb. Ernähr. Planze 34, 77-816, 1938.

Blenkinsop, A. A new volumetric method for the estimation of sodium. Jr. Agr. Sci. 20:511-516, 1930.

Bushnell, T. M. Quick tests for phosphorus and potassium in relation to soil survey work. Am. Soil Survey Assoc., Rept. 15th Ann. Meeting, Bull. 16, 76-80, 1935.

Chamot, Emile M., and Mason, Clyde Walter. Handbook of chemical microscopy. Vol. II. John Wiley and Sons, Inc. New York City, N. Y., 1931.

Depardon. Cultivation of potatoes. Recherches Fertilisation. Sta. Agron., Ministére Agr. (France) 10, 116-19, 1937.

Eckstein, Oscar, Bruno, Albert, and Turrentine, J. W. Potash deficiency symptoms. Verlagsgesellschaft für Ackerbau M.B.H. Berlin S.W. 11, 1937.

Gedroiz, K. K. Soil absorbing complex and the absorbed soil cations as a basis of genetic soil classification. Peoples Commissariat of Agriculture, Agrochemical Division, Paper No. 38, Leningrad, 1925. (Translation by S. A. Waksman for U.S.D.A.)

Gericke, S. Distribution of phosphoric acid and potassium in soils. Z. Angew. Chem. 41, 52-6, 1928.

Gisiger, L. Influence of soil reaction on the solubility of nutrients by the Neubauer and Dirk methods. Zuckerrübenbau. 14, 132-40, 1934.

Scharrer, K., and Schropp, W. Potassium to iron antagonism in plants. Z. Pflanzenernähr. Düngung Bodenk. 28a, 158-72, 1933.

Schreiner, O., and Skinner, J. Ratio of phosphate, nitrate and potassium in absorption and growth. Bur. of Soils, U. S. Dept. Agr. Washington, D. C. Botan. Gaz., 50, 1-30, 1911.

Shibuya, K., and Torii, T. The antagonistic action between potash and alkaline earths for plant growth. J. Sci. Soil and Manure. (Japan) 9, 411-24, 1935.

Smolík, L. Electrodialyzable potassium and phosphorus and Neubauer's method. Věstník Československ. Akad. Zemědělskí 10, 312-14 (315-16 in English), 1934.

Stoklasa, J. The influence of the potassium ion on the development of the sugar beet plant. Oesterr.-ung. Z. Zuckerind. 44, 504-28, 1915.

Thomas, W. The conception of balance with respect to the absorption of nitrogen, phosphorus and potassium by plants and the influence of the level of nutrition. Science 72, 425-7, 1930.

Thomas, W. Absorption, utilization and recovery of nitrogen, phosphorus, and potassium by apple trees grown in cylinders and subjected to differential treatment with nutrient salts. J. Agr. Research 47, 565-861, 1933.

Thornton, S. F. Experiences with the Neubauer method for determining nutrient deficiencies in soils. Jr. Amer. Soc. Agron. 23, 195-208, 1931.

Thornton, S. F. Soil and fertilizer studies by means of the Neubauer method. Indiana Bulletin No. 399, March 1935.

Thornton, S. F. "Root Solubility" of the essential elements in the soil as an indication of availability. Soil Sci. Soc. Am., Proc. I, 125-9, 1936.

Thun, R. Experiments on the Neubauer method and on the easily assimilated nitrogen. Z. Pflanzenernähr. Düngung u. Bodenk. 16a, 257-83, 1930.

Vanatta, E. E. Report on availability of potash. J. Assoc. Off. Agr. Chem. I, 24-6, 1915.

van den Honert, T. H. Physiology of nutrition of the sugar cane. I. Arch. Suikerind. 40, III Mededeel. Proefsta. Java-Suikerind. 1539-608, 1932.

Wilcox, L. V. Determination of potassium. Ind. and Eng. Chem., Anal. Ed. Vol. 9, No. 3, 136-38, 1937.

****
*****
***
*