



The Winogradsky test for determining plant food deficiency in Montana soils
by Charles Robert Johnson

A THESIS Submitted to the Graduate Committee In partial fulfillment of the requirements for the
Degree of Master of science In Botany and Bacteriology at Montana State College
Montana State University
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Abstract:

1. The most Important advantages of this test are: (a) the short time required for its completion, (b) greater control of external factors which limit the value of results obtained from field experiments (c) relative Inexpence of the method, (d) a great number of samples can be tested before the planting season, (e) close correlation of the teat remits to field results.
2. Seven-hundred and fifty samples sere tested over a two year period and 65% of them showed a phosphorous deficiency ranging from moderate to very deficient, 22% showed a slight deficiency, 10% showed no deficiency, end 3% wore indeterminate.
3. The correlation of the Rinogradsky test and the field results in the esse of sugar bests was 95%. Soil tested from a phosphate plot after a crop of sugar beats had been renewed showed a decided phosphate deficiency, indicating that the sugar beets removed a good deal of the phosphorous applied.
4. The correlation of the Winogradsky teat and field results In the ease of alfalfa was 80% over the two year period. The content of phosphorous In the plant increased In proportion to the increase In yield of alfalfa.
5. The correlation of the laboratory and field results fbr Irrigated Wheat fbr the 1931 season was 73%. In some cases the grain on the phosphate plot matured from a week to ten days earlier than the grain on the check plot.
6. No correlation between laboratory and field results was observed In the ease of beans. It appears that a good yield of beans can be obtained from a soil low In phosphorous.
7. The percentage of Montana soils deficient In potash is very low. Only one soil showed a deficiency of potash alone. Fifteen per cent of the soils Whowed a deficiency Cf potash In combination with phosphorous.
8. Many western Montana soils appear to be lacking in Azotobacter and are also acid In reaction.
9. Inoculation of a soil containing no Azotobacter by a soil known to contain many Azotobaeter proved In general more satisfactory than the Inoculation of the soil by a pure eul tore of Aaotobacter.
10. Acid soils were brought to the neutral point by the addition of CaCO_5 . Neutralization of the soil plus inoculation brought positive results from previously Indeterminate soils. In some cases where the soil was neutral inoculation alone gave positive results.
- 11* Gypsum (CaSO_4) particularly In ease red soils from Sanders county produced good Azotobacter growth when used In combination with phosphorous, where phosphorous alone gave no results* 18* One hundred samples were tested by the Truog phosphorous method end no definite correlation was found between the Truog and Wlnogradahy methods regarding phosphorous availability* The exact

reason for this lack of correlation is undetermined* 13* Sugar used in place of corn starch as a source of energy for the bacteria, produced a film over the surface of the solid plaque, making an estimation of the number and type of the bacterial growth impossible. Sugar failed to produce growth when used in a peptone oil, Alch also did not respond to starch*

THE WINOGRADSKY TEST FOR DETERMINING PLANT FOOD

DEFICIENCY IN MONTANA SOILS

by

CHARLES R. JOHNSON

Walsh Research Fellow in Agriculture, 1931-32

A THESIS

Submitted to the Graduate Committee in partial fulfillment
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INTRODUCTION

The problem of determining the plant food deficiencies of soil is gradually increasing in importance, due to some extent to the fact that our extensive frontiers with their countless acres of virgin soil have practically all disappeared. The problem of soil fertility can no longer be solved by moving to a new section where the soil still retains its natural fertility.

A great number of the once productive farms of New England, and the Southern and Middle Western states are today practically worthless, because they were cultivated until they reached a depleted condition. The cost of restoring them being almost prohibitive.

Montana soils are much nearer the virgin state than those mentioned above, and have until recently produced exceptionally well. Although it has been noticed for a number of years that an application of barnyard manure on Montana soils increased production. It appears now that many Montana farms have arrived at the point where the reserve of some of the mineral plant food in an available form, has been consumed, and that the crop demands are exceeding the supply, the result being a noticeable reduction in yields in recent years.

The problem of determining these deficiencies of the soil is probably not one of soil type or locality, but of the individual field, depending upon the crop history and general method of farming.

The Winogradsky bacteriological test for mineral deficiencies

of soil (especially regarding phosphate deficiency) has come into prominence. The purpose of this work was to determine the applicability of the test to Montana soils, and to overcome previous difficulties encountered in testing Montana soils by this method.

The work was done in the bacteriology laboratory of the Agricultural Experiment Station of the Montana State College in 1931-32 under the supervision of Professor H. E. Morris and Dr. D. B. Swingle, in cooperation with the Chemistry Department of the Agricultural Experiment Station. It was a continuation of studies begun as a bachelor's thesis and was made possible by the provisions of the Senator Walsh Research Fellowship.

METHODS OF TESTING SOIL FOR MINERAL DEFICIENCIES

Neubauer Test

Rye plants are grown in the laboratory for 14 days upon the soil under examination, and from a chemical analysis of the plants the shortage of phosphate and potash is determined (12). Because of the time and expense involved it would not be feasible to test any great number of samples before the planting season. However, the results obtained from this method appear to be quite dependable.

Chemical Analysis

The chemist in his soil analysis by colorimetric methods employs weak acids as solvents in an effort to imitate the action of plant roots in dissolving the mineral particles. This gives only an approximate idea of the amount of material which is in a form that plants can

utilize. The mineral food which a growing plant can utilize and that which is dissolved by chemical methods may be quite different. A chemical analysis, therefore, is valuable only where a marked deficiency or excess exists, and to show the potential amount of certain minerals in the soil.

Experimental Plots

Different fertilizers at varying rates are applied to experimental plots which are then planted to growing crops. At the end of the season, yields are taken and conclusions drawn as to the relative benefits of the treatments. This method is limited in its general application, and possesses little value for the individual farmer, unless he has an experimental plot for each field. This point is understood when consideration is given to the fact that every field has its own deficiencies, depending upon crop history and farming practices with regard to that field.

Colorimetric Methods for Determining Phosphorous

In 1920, Deniges (5) published a method for the colorimetric determination of phosphorous present as phosphate, by means of a blue color produced when a reducing agent is added to an acid solution of ammonium molybdate containing inorganic phosphates. The above reaction is the basis for colorimetric methods for determining phosphorous.

Chapman (3) states, regarding the colorimetric methods of determining phosphorous in soils, that there is a necessity for further

work regarding the possible influence of such concentrations of salts as may be found in the soils and irrigation waters of semi-arid regions on the accuracy of tests of this type. He further states that silicon dioxide and the ferrous ion, as well as nitrates and sulphates under some conditions influence the results of this test.

Hibbard (7) states the following regarding the Truog colorimetric method: (19) "of all equilibrium methods Truog's is perhaps the simplest, cheapest, quickest and generally the most useful. It has the defects of other equilibrium methods, and also the large portion of solvent to soil used in this method has a leveling effect, tending to make poor soils seem better, and rich soils seem poorer. He also states that the K_2SO_4 used in the Truog solvent changes the solubility of PO_4 in some soils more than in others, again tending to misrepresentation."

Winogradsky Soil Test

Historical

Greaves (6) gives the following historical account: "The first one to hint at the fact that microorganisms in the soil might take part in the process of nitrogen-fixing was Boussingault in the middle of the nineteenth century. Thirty years later Hellriegel and Wilforth made the discovery of nitrogen-fixing by symbiotic organisms. In 1883 Berthelot proved conclusively the presence in the soil of chlorophyll-free bacteria capable of fixing atmospheric nitrogen. This

discovery interested Winogradsky, who worked with fifteen separate species of soil bacteria and discovered that the power of fixing nitrogen was not general among the soil microorganisms, but confined to a few special forms. Following this, Eason did much work with a spore-bearing bacillus. In 1901, Beijerinck furthered the history immensely by his discovery of a new group of large aerobic bacilli which he called Azotobacter. He, working with von Delden, believed that the nitrogen-fixing power of Azotobacter depended on other soil organisms. Later Gerlach and Vogel isolated one of Beijerinck's Azotobacter in pure culture and showed that it was capable of active nitrogen-fixation.

Beijerinck and von Delden had described A. chroococcum and A. beijerinckii, and A. woodstownii. Later Lohm & Westermann described A. vitreum. All workers have found A. chroococcum to be the most widely distributed in the soils so far studied."

A test which gives accurate information as to available plant food and requires a short enough time to be of practical value was worked out by Winogradsky and Ziemiecka of the Pasteur Institute, of Paris, France. These workers discovered that the plant foods such as phosphate, potash, and lime, which are essential to plant growth, are also essential to the growth of the Azotobacter, nitrogen-fixing bacteria, and that these bacteria will not grow where the soil is deficient in these foods. Therefore, different fertilizers, singly or in combination, are added to the soil samples and the results

compared with a check having only distilled water. In this way the soil deficiencies can be determined. J. Ziemecke is among the first investigators to make practical use of the soil plaque to determine mineral soil deficiencies. She employed it successfully in her studies of the phosphate and lime needs of Polish soils. Guittoneau used it successfully on some orchard soil in France. The plaque method confirmed results of the more laborious chemical studies. Niklas used it in the determination of the lime and phosphorous requirements of certain German soils.

This method was used experimentally in Colorado in 1927 and was adopted by some of the sugar companies in 1929, and is now being used in a practical or an experimental way in several other states.

Discussion of Azotobacter

In the American system of classification, as given in Bergey's Manual (1), Azotobacter is placed in the family Nitrobacteriaceae, and represented by the species A. chroococcum Beij.

In general Azotobacter are relatively large rods, measuring 1 to 2 μ thick and 1.5 to 3 μ long and even cocci, sometimes almost yeast-like in appearance. They are either motile or non-motile. If motile, they have a single or a tuft of polar flagella. Lohnis and Smith (11) observed that Azotobacter, in common with many other bacteria, pass through a life cycle which is not less complicated than

those of other microorganisms. They multiply not only by fission, but by the formation of gonidia. Investigation has shown that these nitrogen-fixing organisms are of very wide distribution. Lipman and Burgess (10) studied 46 soils from all over the world and found Azotobacter in about one-third of the soils. Several hundred Utah soils were examined and all were found to contain Azotobacter. They also occur more frequently and in greater numbers in cultivated than in virgin soils. These organisms are confined almost entirely to the first three feet of soil and are not active in the upper few inches. They are also found in both fresh and salt waters. According to Itano (8) they are found generally in warm climates where humus is almost lacking and the soil is neutral or alkaline and very few are found in cold climates except where wood ash or CaCO_3 is applied.

The conditions for the growth of this organism are quite well defined. One of the foremost conditions determining the distribution of the organism is the basicity of the soil, that is, its calcium or magnesium carbonate content as the organism grows very well in the presence of either of these. Greaves (6) and Yamagata and Itano (26) give some interesting data concerning the distribution of Azotobacter relative to the reaction of the soil. A. chroococcum is most widely distributed and is in the alkaline soils; A. biejerinckii is less common and in nearly neutral soils; and A. vinelandii, least common and also in the alkaline soils. The optimum hydrogen ion content

should lie between P_H 6.65 and 7.7, being quite high for A. vinelandii and quite low for A. beijerinckii.

Regarding their nutrition, Greaves (6) states that these organisms require essentially the same elements as do the higher plants, which fact has made them especially useful in determining mineral deficiencies of soil. Phosphorous is the most essential food for Azotobacter and in some soils is the limiting growth factor. The other elements, namely, carbon, hydrogen, oxygen, nitrogen, potassium, sulphur, calcium, manganese, and iron are also required.

Azotobacter obtains its energy for nitrogen-fixation through the decomposition of organic compounds, especially carbohydrates. Other materials often have a stimulative effect on Azotobacter. Cellulose is a valuable source of energy but must be decomposed first. Sanborn and Hamilton (16) say that the Azotobacter itself has a stimulating effect on the cellulose destroyers, a fact which they determined by the increased change in reaction. However, Skinner (18) refutes this and suggests that A. chroococcum merely utilizes the by-products formed in cellular decomposition thus bringing about the reaction change. Itam (8) has said that vitamine B and nucleic acid added to a medium exert a marked stimulating influence on Azotobacter's growth and fixation of nitrogen. A later work by Werkman (23) says that vitamin B concentrate is what gives the stimulating influence. Thus, we can see that the quantity of nitrogen fixed may be influenced by organic compounds to some extent.

The knowledge of the metabolism of Azotobacter is not very definite. It is known that Azotobacter oxidize various carbohydrates and with this energy build up complex nitrogen compounds. Greaves (6) gives an analysis of Azotobacter cells which shows them to contain, when grown on dextrin agar and rapidly dried at 30° C, 6.63% of water, 4.12% of ash, 12.92% of protein and 76.23% of nitrogen free material. Bonazzi (2) in studying the metabolism of these organisms said that C:N ratio is an inconstant value; that the nitrogen-fixing capacity of the organism seems to be a function of secondary importance in the cell economy, and that in general the metabolism was not yet well understood.

Most species of Azotobacter produce pigments. These vary from brown to black of the A. chroococcum auth. to yellow or orange of the A. vinelandii auth. This pigmented film usually develops in from three to seven days on the culture medium. It is produced and retained within the bacterial cell, occurring in neither capsule nor medium.

The optimum temperature for nitrogen-fixation by Azotobacter is at 28° C, and the limits of activity lie between 9° C, and 33° C. We incubated our samples at a temperature of 30° C.

The test which is described in the following pages is based on the activities of Azotobacter as described above.

Materials and Methods

The materials used consist of a stiff spatula for mixing the soil after wetting; small crystallizing dishes or metal capsules which hold

a little less than 50 g. of soil, the depth should about equal the diameter of the dish. A flexible bladed spatula for packing the soil into the capsules. An incubator which can be kept at a constant temperature of from 28° to 30° C; large, covered evaporation dishes in which to place the capsules for incubation. A mixing can was used, (Plate I), this consisted of a square tin box about 6 inches on each side, set on a stand and equipped with a handle for turning the box. Round, wax papered, 2 quart boxes were used as soil containers. A 20 mesh screen was used for sifting the soil before adding the chemicals. Mannitol agar prepared according to Levine and Schoenlein (9) was used in all culture work.

The soil was ground and a 200 g. portion taken from the sample, to this was added 10 g. of corn starch ($2\frac{1}{2}$ g. per 50 cc. of soil). The portion was thoroughly mixed in the mixing can and screened through the 20 mesh screen. Four 50 g. portions were weighed out. To Number one was added distilled water, to Number two .3 g. $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$, to Number three .15 g. K_2HPO_4 and to Number four 50 g. portion was added .15 g. of K_2SO_4 , enough distilled water being added to bring the soil to the plasticity of modeling clay. The three chemicals were added in solution. The specified amount for each 50 g. of soil was dissolved in 10 cc. of distilled water. The surface of each plaque was smoothed over with a spatula dipped in distilled water. The plaques were placed in a moist chamber, and incubated at 28° to 30° C, for 72 hours. The moist chamber into which the plaques were placed

was a large crystallizing dish with a cover and about $\frac{1}{2}$ inch of water in the bottom of it. A piece of absorbent paper was fitted into the top of the moist chamber to prevent drops of condensation water from falling on the plaques of soil.

Sugar (sucrose) was used as a source of energy in the testing of some soils in the place of starch.

The hydrochloric acid test for free carbonates was applied to all soils tested during the present year (tables 1 - 22). The Truog acidity test (20) was applied to those soils which gave a negative carbonate test. To those soils which proved to be acid 5 g. of CaCO_3 was added to each 50 g. sample to bring the soil to neutrality.

A number of soils were inoculated with either 2 g. of soil or with 1 cc. of a bacterial suspension of *Azotobacter* to obtain a comparison of results from the two kinds of inoculations. The soil used for the inoculation with one which had previously shown a good growth of *Azotobacter*. The culture of *Azotobacter* was one which had been grown on Mannitol agar for 72 hours and suspended in 100 cc. of physiological salt solution. One cc. of the suspension was used for each plaque. The culture was obtained by plating out from a culture on a soil plaque, then transferring the culture from the plate to a slant tube of Mannite agar. Jones' Modified Ashly's Mannitol Solution [Levine and Schoenlin (9)] was used in plating and culturing. To each 1000 cc. of the Jones' Modified Ashly's Mannitol Solution was added 12.5 g. of agar. This solution was made up as follows:

Distilled water	1000 cc.
Mannitol	20 g.
K_2HPO_4	.2 g.
$MgSO_4$	.2 g.
NaCl	.2 g.
$CaSO_4$	.1 g.
$CaCl_2$	5.0 g.

One hundred soil samples (tables 1 - 22) which had been tested by the Winogradsky method, were tested by the use of the La Motte-Truog phosphorous outfit to obtain a correlation between the two tests regarding phosphorous deficiency.

All available soil samples from which no results were obtained last year were retested. The acidity of these samples was adjusted and they were inoculated with either 2 g. of a previously tested soil or with 1 cc. of a bacterial suspension of Azotobacter. In some cases .3 g. of gypsum ($CaSO_4$) was added to each 50 g. of soil.

In recording the amount and character of the bacterial growths on the plaques a code was formulated, the code being as follows:

- 1 meaning 1 to 6 colonies (few)
- 2 meaning 7 to 20 colonies (several)
- 3 meaning 20 to 60 colonies (many)
- 4 meaning 60+ colonies (numerous)
- t meaning transparent
- w meaning white

b meaning brown or black

s meaning small

m meaning medium

l meaning large

f meaning film

Dr. Sackett's (11) method of interpreting results was obtained and it was found that our own interpretations of plant food deficiencies corresponded quite closely to those of Dr. Sackett.

The following interpretation was made of the bacterial growths on the soil plaques (as illustrated by Fig. 1 & 2, Plate II):

Class 1. Very deficient:

Untreated plaque - colonies none or less than 1% of number on treated plaque; colonies extremely small.

Treated plaque - few to numerous, distinct and vigorous colonies.

Class 2. Moderately deficient:

Untreated plaque - colonies few to as many as treated plaque, but very much smaller and weaker in development; none approaching size of colonies on treated plaque. Pigment often less to none.

Treated plaque - colonies few to numerous, distinct and vigorous.

Class 3. Slightly deficient:

Untreated plaque - colonies as numerous as treated, but smaller and less vigorous.

Treated plaque - colonies few to numerous, distinct and

and vigorous.

Class 4. No deficiency:

Colonies on both treated and untreated approximately equal in number and development.

The soils tested were representative samples of the fields and were taken according to the following directions:

First.- In each 40 acres or less at least five spots were selected for sampling where native vegetation or crop growth was normal, and in a like manner the same number of spots in the same field where there was a minimum crop growth were selected.

Second.- The kind of crop growth was noted on the spots, sampled and recorded on the information blank.

Third.- Growing vegetation and undecomposed vegetable matter was removed from the surface of the soil where samples were taken.

Fourth.- A soil auger was used and samples were taken representing the soil from the surface to a depth of one foot from at least five spots where growth was normal. All borings were placed in a clean container, mixed well with the hands, and four to five pounds taken for a sample. In a like manner samples were taken from five more spots showing a minimum growth.

Fifth.- A spade was used when a soil auger was not available. Holes were dug in the spots selected a foot deep and from a vertical side of each hole, was cut, with a spade, a section about two inches thick from the surface to the bottom of the hole. These samples were treated in the same manner as those taken with an auger.

Certain essential information was obtained regarding the soil by the collector answering the questions on the following information blank.

Information Blank

Date of sampling _____ day of _____ 19____.

Name of sender _____ City _____

County _____ State _____

Location of land _____ of Sec. _____ T. _____

R _____ Size of field _____

Is plant growth normal and uniform over the tract, or does it vary _____

Does alkali show in spots _____

Number of years cropped _____ Is it irrigated or dry _____

If irrigated, what rotation has been followed _____

If dry land, state method of farming, for example, fallow and crop, 2 years crop and fallow, continuously cropped. _____

Name crop and give approximate yields for the past five years. _____

Has the land been manured _____ How often _____

Kind of manure _____

Number of samples mixed to make composite _____

Remarks:

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The form given below was adopted for reporting the results
of the test to the owner.

Winogradsky Soil Test

Name _____ Sample No. _____

Address _____ Date _____

Fertilizers applied _____

Results of Test

Potash _____ HCl test _____

Phosphorous _____ Truog Acidity Test _____

Combination of Potash and Phosphorous _____

Gypsum _____

Lime _____

Recommendations _____

Experimental Work and Data

The results of this work showed a decided phosphate deficiency in Montana soils. Of the 750 soils tested from a total of 34 Montana counties over a two year period, 65% of them were shown to be from moderately deficient to very deficient in phosphorous (tables 23 and 24), by the Winogradsky method. Twenty-two per cent showed a slight deficiency, 10% no deficiency, and 3% were indeterminate. Over 22% of the 1930 soils were indeterminate and all of these samples available were retested in 1931 with some modification in technique with positive results from practically all of them retested. The 1931 results included but two samples from which no results could be obtained, these were samples of a peat soil.

The percentage of Montana soils deficient in potash is very small compared to that of phosphorous (tables 1 - 22). In only one of the soils was there a deficiency shown with the addition of potash alone. However, in about 15% of the soils a better growth of *Azotobacter* was obtained by adding a combination of potash and phosphorous, than where phosphorous alone was added.

The correlation of the field yields of sugar beets obtained by the Chemistry Department with the Winogradsky test over the two year period was approximately 95%. The 1930 average was lower than this since several indeterminate samples were included in this group. The indeterminate samples of this group were retested during the present year, and the 1930 correlation was raised as a result of this re-testing. Five experimental plots with sugar beets were set out in 1931.

The Winogradsky test correlated 100% with these five plots (tables 1-15-22). Increases in the yield of sugar beets by the application of phosphorous ran as high as 416% in one field. The average increase in 19 fields being 85%.

In practically every case where a deficiency was shown in the check plot and a good tonnage of beets grown in the phosphate plot, a soil sample taken from the phosphate plot after the beets were removed at the end of the season, showed a decided phosphate deficiency. This would lead to the assumption that the crop of sugar beets used up a good deal of the phosphorous applied at the beginning of the growing season. Sackett (15) in his recent bulletin stated that a 12 ton crop of sugar beets removes 54.93 pounds of Treble Super-phosphate per acre each year.

The correlation of the field and laboratory tests in the case of alfalfa for the two year period was 80%, being lower than in the case of sugar beets. The average increase from 43 fields was 18% from the application of Treble Super-phosphate. A four ton crop of alfalfa removes twice as much phosphorous as a 12 ton crop of sugar beets.

The correlation in the case of irrigated wheat for the 1931 season was 75% (tables 1 - 22). A fifty bushel crop of wheat with $2\frac{1}{2}$ tons of straw removes 81.30 pounds of Treble-Super-phosphate per acre. In many cases the grain on the phosphate plot matured from a week to ten days earlier than the grain on the check plot.

A few test plots were laid out for beans during the 1931 season, however, the Winogradsky test results (tables 1 - 22) did not

correlate with the bean results. It appears that a good yield of beans can be obtained from soil low in phosphorous.

From Dr. Sackett (14) it was learned that a pure culture of Azotobacter would produce a growth in soils lacking in these bacteria. Previous to this a small amount of soil from a soil known to contain many Azotobacter, had been used for inoculation in our laboratory. A comparison was made of the two methods of inoculation, by inoculating plaques of the same soil with a pure culture and with soil. Two grams of soil was used to inoculate 50 grams of the soil being tested. The bacterial inoculum for each 50 gram of soil consisted of 1 cc. of a pure culture suspension in physiological salt solution. The culture being 72 hours old before placed in suspension. Soil inoculation in comparison with bacterial inoculation gave in general, better results, particularly more vigorous colonies. The Azotobacter in a soil has been found to be fully as active after the soil has been kept in the laboratory in a dry condition for two years. Soil inoculation also saves a good deal of time in the manipulation of the test.

Soils which are acid must be brought to the neutral point to allow the proper development of the Azotobacter introduced. Concentrated hydrochloric acid applied to a small portion of a soil will determine whether or not a soil possesses free carbonates as evidenced by the CO_2 evolved. Soils which gave no indication of free carbonates were tested for acidity by the Truog method. If a soil proved to be acid beyond the Azotobacter limit of development 5 g. of CaCO_3 were added

to each 50 gram plaque of soil. This gives an excess of CaCO_3 , however, Sackett (15) observed no retardation of Azotobacter growth by using as much as 33% of CaCO_3 . The excess of CO_3 brings about a neutralization in a shorter length of time.

In the case of some of the soils from western Montana gypsum (CaSO_4) was found to produce growth in combination with phosphorous, where the phosphorous alone gave no results. This was particularly true of a red soil from Sanders County.

Sugar has been suggested for soils which do not seem to possess the necessary anaerobes to make the corn starch available for Azotobacter. Sugar was used in a few samples in comparison with starch. A continuous film was formed over the surface of the plaque containing sugar, whereas the surface of the plaques containing starch had characteristic, distinct colonies. The film on the plaque containing sugar made the estimation of the number and type of colonies impossible. Sugar was used in a troublesome peat soil and gave no results.

The Truog phosphorous test was applied to one hundred of the soil samples (tables 1 - 22), and no definite correlation was found between the two phosphorous tests regarding phosphorous availability.

Two hundred and sixty-six soil samples were tested for phosphorous in 1931-32 by the Winogradsky method as described in the preceding pages. This data is presented in detail in tables 1 to 22, and arranged alphabetically by counties. Table number 23 gives a summary of the 1931-32 soils tested. Table number 24 gives a summary of the data obtained from the Winogradsky test in 1930-31.

Table No. 1

Results of tests on soil samples from Big Horn county in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
505	R. McKittridge	Alfalfa ck plot	I	1 (P&K) very	75	fair	+
506	" "	Alfalfa P ₂ O ₅ plot	I	2 (mod)	75	good	+
507	Geo. Mehling	Sugar beet - beans ck	I	1 (very)	75	good	+
508	Carl Bowman	Alfalfa ck	I	1 (very)	100	fair	?
615	Geo. Crouch	Grain, Alfalfa, Beans	I	3 (sl)			
616	" "	Grain, Alfalfa, Beans	I	3 (sl)			

Summary: Total Samples Phosphate deficiency

Class 1 - 2 - 3 - 4

6

3 1 2 0

Table No. 2

Results of tests on soil samples from Big Horn county in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Trueg test P ₂ O ₅	HCl test	Corre- lation in field
463	H. B. Bonebright	Wheat, Potatoes, rotation	I	2(P&K)mod		good	
464	Sharples	Sugar beets - ck plot	I	2(P&K)very		good	
465	Sharples	Sugar beets - P ₂ O ₅ plot	I	3(P&K) sl		good	

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

3

0 2 1 0

Table No. 3

Results of tests on soil samples from Carbon county in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
373	O. F. Yedlicka	Wheat, Bean, Barley-ck plot	I	2(mod)			+
503	R. J. Putnam	Beans 1923-31 ck	I	1(very)	25	*	-
504	O. F. Yedlicka	Beans ck	I	1(very)	100+	good	?
610	Hoy Reams	Beans ck	I	2(mod)	75-		
611	" "	Beans P ₂ O ₅ plot	I	2(mod)			
612	" "	Beans Am-Phos. plot	I	2(mod)	25-		

*503 - Truog acidity test - neutral

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

6

2 4 0 0

Table No. 4

Results of tests on soils from Cascade county in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
394	Perry Herron	Alfalfa	I	2(mod)	50+	-	+
453	L. Kline	Alfalfa 7 yr. potatoes '31	I	1(v.def.)		good	+
454	" "	Potatoes	I	3(sl)		good	
455	" "	Potatoes		3(sl)		good	
456	" "	Wheat	I	1(v.def.)	10-	good	+
457	" "	Wheat		2(mod)		good	
458	" "	Wheat		1(v.def.)	10-	good	+
459	S. Hansen	Alfalfa	I	2(mod)		good	+
460	" "	Alfalfa	I	3(sl)		good	
516	W. O. Chowen	Various crops	I	3(sl)		good	
517	" " "	Wheat, Potatoes, Barley	I	2(mod)		good	
518	" " "	Summer fallow	D	3(sl)		good	
519	" " "	Fallow	I	3(sl)		good	
520	" " "	Native pasture	D	2(mod)		good	

#394 - Truog acidity test - neutral

No indication of potash deficiency in any of the samples.

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

14

3 5 6 0

Table No. 5

Results of tests on soil samples from Custer county in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Corre- lation in field
473	A. C. Dorr	Barren Spot	-	1(very)	25+	fair	
552	John Herzog	Alfalfa	I	1(very)	50+		
553	" "	Corn, corn	I	2(mod)	50+		
554	" "	Rye, fallow	D	2(mod)	75+		
555	Wm. Tibbeles	Alfalfa 1929-31	I	1(very)			
556	Carl Herzog	Subsoil exposed, fallow	I	2(mod)	100+		
557	O. C. Haynes	Alfalfa, sorghum	I	1(P&K)very	100+		
558	Miles City Reh. Co.	Alfalfa, barley	I	1(very)	75+		
559	" " " "	Oats, flax	D	2(mod)	75-		
560	A. Hogg	Alfalfa 1930-31	I	2(mod)	75+		

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

10

5 5 0 0

Table No. 6

Results of tests on soil samples from Dawson county in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
570	W. E. Martin	Wheat	D	3(sl)			
571	V. Jones	Corn, Wheat	D	3(sl)			
572	M. Vander Hoef	Oats, Fallow	D	3(sl)			
573	V. Jones	Corn	D	2(mod)			
574	A. L. Matchette	Wheat, Corn	D	3			
575	L. Jones	Wheat, Corn	D	2(mod)			
576	H. Glick	Wheat, Corn	D	3(sl)			
577	Mayers	Fallow, Corn, Wheat	D	3(sl)			
578	I. Jones	Wheat, Fallow	D	3(sl)			
579	C. Dickerson	Wheat, Fallow	D	2(mod)	50+		
580	Hans Oakland	Oats, Corn	D	3(sl)	50+		
581	Lars Slagsvold	Alfalfa, Alfalfa	D	3(sl)	75		
582	Youngblood ranch	Oats, Wheat	D	3(sl)	50		

Summary: Total Samples Phosphate deficiency

Class 1 - 2 - 3 - 4 - ?

13

0 3 9 0 1

Table No. 7

Results of tests on soil samples from Fergus County in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
418	A. W. Eiselein	Garden	I ?	2(mod)	50+	good	
541	F. T. Colver	Alfalfa 25 yr.	I	3(sl)	75+		
542	" " "	Alfalfa 35 yr.	I	3(sl)	50+		
543	Eastman Ranch	Fallow, Wheat	D	3(P&K)sl	50+		
544	W. N. McElroy	Wheat, Fallow, Barley	D	3(sl)	75+		
545	Chas. Gladsen	Fallow, Wheat	D	3(P&K)sl	50+		
546	Ortho Dorrman	Barley	D	3(sl)			
547	" "	Fallow, Winter wheat	D				
548	Ben Guidinger	Fallow, Wheat	D	3(sl)	50		
549	Wm. McKenzie	Fallow, Oats	D				
550	J. W. Hershberger	Fallow, Wheat	D	4(none)	100+		
551	E. S. Boller	Fallow, Wheat	D	3(sl)	75		

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

10

0 1 8 1

Table No. 8

Results of tests on soil samples from Flathead County in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Corre- lation in field
345	H. Hetland	Wheat	D	3(sl)			
346	J. Ficken	Wheat	D	2(mod)			
347	O. Reed	Wheat	D	2(mod)			
348	Wm. Lynch	Wheat	D	1(P&K)very			
349	H. Taylor	Wheat	D	2(mod)			
350	H. Linden	Lettuce	D	2(mod)			
351	D. Sullivan	Wheat	D	2(mod)			
352	C. Buck	Wheat	D	2(mod)			
353	G. Wendt	Wheat	D	2(mod)			
354	C. E. Willson	Potatoes	D	3(sl)			
355	E. McLain	Potatoes	D	3(sl)			
356	R. Barnard	Alfalfa	D	2(mod)			
357	R. Barnard	Potatoes	D	2(mod)			
540	Mont. Soldiers Home	Garden	I	3(sl)			

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

15

1 10 4 0

Table No. 9

Results of tests on soil samples from Callatin County in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truce test P ₂ O ₅	HCl test	Correlation in field
369	E. A. Black	Alfalfa few years	I	2(mod)			
370	" " "	Alfalfa	I	2(mod)			
371	Tudor	Alsike & timothy	I	2(mod)			
372	"	Alfalfa	I	2(mod)			

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

4

0 4 0 0

Table No. 10

Results of tests on soil samples from Glacier County in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	TrueG test P ₂ O ₅	HCl test	Corre- lation in field
376	J. L. Miller	Alfalfa	I	2(mod)			
391	Calder	Alfalfa ok.	I	2(mod)			

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

2

0 2 0 0

Table No. 11

Results of tests on soil samples from Lake County in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	Truog acidity test	Correlation in field
474	T. Wold	Alfalfa ck.	I	2(mod)		sl.	-
475	" "	Alfalfa P ₂ O ₅ plot	I	2(mod)		sl.	-
476	J. Hendrickson	Alfalfa ck	I	2(mod)		sl.	
477	" "	Alfalfa P ₂ O ₅ plot	I	2(mod)		sl.	
478	G. Johnson	Alfalfa ck	I	3(sl)		quite	
479	" "	Alfalfa P ₂ O ₅ plot	I	3(sl)		quite	
480	L. Atkinson	Alfalfa ck	I	2(mod)		sl.	
481	" "	Alfalfa P ₂ O ₅ plot	I	4(none)		sl.	+
482	B. B. Wolfinger	Alfalfa ck	I	4(none)		quite	
483	" " "	Alfalfa P ₂ O ₅ plot	I	3(mod)		quite	-
484	L. L. Benington	Wheat ck	D	2(mod)		*	+
485	" " "	Wheat P ₂ O ₅ plot	D	3(sl)		quite	
486	Lake County 1	Fallow	D	2(mod)		sl.	
487	Lake County 2	Fallow	D	3(sl)		sl.	
617	A. L. Fryberger	Red Clover	I	3(sl)			
618	J. H. Newton	Red Clover	I	3(sl)			
619	" " "	Red Clover	I	3(sl)			

*484 - HCl reaction slight.

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

17

0 7 8 2

Table No. 12

Results of tests on soil samples from Missoula County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Corre- lation in field
420	Ed Donlan	Fallow, Oat stubble	D	1(very)			
421	" "	Fallow, Wheat	D	1(very)			
422	" "	Oat stubble	D	1(very)			
423	" "	Summer fallow	D	1(very)			
424	" "	Unplowed land	D	2+(mod)			
425	" "	Summer fallow	D	1(very)			

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

6

5 1 0 0

Table No. 13

Results of tests on soil samples from Musselshell County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
401	B. Neace	Wheat fallow	D	4(none)			
402	" "	Alfalfa	I	2(P+K)mod	150	good	
403	Jacob Bros.	Alfalfa		3(sl)			
404	Thomas & Sons	Alfalfa	I	2(mod)			
405	J. Hougherty	Alfalfa		1(very)			
406	G. Robson	Wheat	D	3(sl)	100	good	
407	C. Eaton	Wheat	D	2(mod)			
408	T. Lee	Wheat, Fallow	D	2(mod)	50	good	
409	" "	Fallow, Wheat	D	1(very)	10	good	
410	H. H. Porter	Alfalfa	I	2(P+K)mod	75+	good	
411	Dr. Morris	Wheat	D	1(very)	75	good	
412	F. Clawson	Alfalfa	I	3(P+K)sl	150+	good	
413	" "	Alfalfa	I	3(sl)	75+	good	
414	J. Rose	Wheat	D	2(mod)			
415	L. Griffinia	Winter wheat	D	2(mod)	75	good	
416	M. Lindstrom	Barley	I	2(mod)	10	good	
417	--	Alfalfa	D	2(mod)			
419	A. Ross	Wheat fallow	D	4(none)			

Summary: Total Samples Phosphate deficiency

Class 1 - 2 - 3 - 4

18

3 9 4 2

Table No. 14

Results of tests on soil samples from Pondera County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Corre- lation in field
359	D. Kooistra	Wheat	D	3(sl)			
360	J. Kokema	Fallow	D	2(mod)			
361	R. Everts	Sugar beets	I	2(mod)			
362	F. Everts	Sugar beets	I	3(sl)			
363	Anderson	Sugar beets	I	1(very)			
364	E. A. Anderson	Oats	D	2(P&K)mod			
365	Scott Ranch	Wheat	D	3(sl)			
366	Mat K	Wheat	D ?	2(mod)			
367	J. Kispin	Fallow	D	2(mod)			
368	Scott Wright	Sugar beet	I	2(mod)			
377	B. Christensen	Wheat, Fallow, ck.	D	3(sl)			+
382	Valiers L&W Co.	Alfalfa 3 yr. ck	I	3(sl)			-
390	B. Christensen	Wheat 1931 ck	D	3(P&K)sl			
392	A. Vermulin	Sweet clover, Wheat 1931 ck.	I	3(sl)			-

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

14

1 6 7 0

Table No. 15

Results of tests on soil samples from Ravalli County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Trueg test P ₂ O ₅	Trueg acidity test	Correlation in field
466	Elgin Heights	Orchard	I	2(mod)	100	sl	
467	Jay Wood	Sugar beets 2 yr.	I ?	4(none)	100+		
468	Dr. Porter	Orchard & Alfalfa	I	2(mod)	25+	sl	
469	" "	Orchard & Alfalfa	I	2(mod)	50+	quite	
470	Hort. Sub. Sta.	Orchard, Garden, Fallow	I	3-(v.sl)	150	sl	
471	" " "	Fallow	I	3(sl)	50+	sl	
472	Elgin Heights	Orchard	I	2(mod)	25+	quite	
488	G. B. Strange	Sugar beets ck	I	1(very)			+
489	" " "	Sugar beets P ₂ O ₅	I	*1(very)			
490	E. V. Doty	Sugar beets ck	I	1(very)			+
491	" " "	Sugar beets P ₂ O ₅	I	*1(very)			

#467 HCl good. #488, 489, 490, 491 HCl fair.

*Soil sampled after beets were harvested.

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

11

4 4 2 1

Table No. 16

Results of tests on soil samples from Richland County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
521	DeYoung #1	Salt grass sod	D	2(mod)	10		
522	" #2	Fallow	I	1(P&K)very	50+		
523	" #3	Sod	D	2(mod)	25		
524	" #4	Alfalfa	I	2(mod)	75		
525	" #5	Sugar beets	I	2(P&K)mod	50		
526	" #6	Alfalfa	I	2(P&K)mod	50+		
527	" #7	Corn	D	2(mod)	50		
528	" #8	Sod	I	1(very)	50+	good	
529	" #9	Sugar beets	I	2(mod)	75+		
530	" #10	Alfalfa	I	1(very)	10-	good	
531	" #11	Weeds	I	2(P&K)mod	10+		
532	" #12	Fallow	I	3(sl)	25+		
533	" #13	Sugar beets	I	2(mod)	25+		
534	" #14	Weeds		?	50+		
535	" #15	Sugar beets	I	3(sl)	50		
536	" #16	Virgin land	D	2(K)mod	75		
537	" #17	Fallow		3(sl)	50+		
538	" #18	Alfalfa	I	2(mod)	100		
539	" #19	Fallow		2(mod)	10+		

Summary: Total Samples Phosphate deficiency

Class 1 - 2 - 3 - 4

18	3	12	3	0
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Table No. 17

Results of tests on soil samples from Sanders County in 1932.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Corre- lation in field
399	C. H. Rittenour	Barberry hedge	I	1(very)	75	sl	
613	B. F. Arness	bare spots	D				
614	" " "	good part of field	D				

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

1

1 0 0 0

Table No. 18

Results of tests on soil samples from Stillwater County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	Truog acidity test	Correlation in field
492	R. Selkirk	Alfalfa 3 yrs. ck	I	2(mod)	75	quite	?
493	" "	Alfalfa 3 yrs. P ₂ O ₅	I	2(mod)	10+	quite	
494	P. Herson	Alfalfa 2 yrs. ck	I	3(P+K)sl	50+	neutral	+
495	" "	Alfalfa 2 yrs. P ₂ O ₅	I	4(none)	100	sl	
496	J. Nickol	Alfalfa ck	I	2(mod)	100	sl	-
497	H. M. Caulwell	Corn in 1930. ck	I	2(P+K)mod	75	sl	
498	W. Caulgrove	Alfalfa 6 yrs. ck	I	3-(v,sl)	75		+
499	" "	Alfalfa 6 yrs. P ₂ O ₅	I	3-(P+K)v.sl	150		
583	Shane	Barley	I	2(mod)	75		
584	F. L. Fahrion	Oats	I	2(mod)			
585	T. Patterson	Wheat, Fallow	D	2(mod)			
586	F. Heily	Wheat	D	2(mod)			
587	B. F. Waltermann	Wheat, Fallow	D	2(mod)			
588	G. Harris	Wheat	D	2(mod)			
589	B. F. Waltermann	Fallow	D	3(sl)			
590	J. H. Murane	Corn	D	3-(v. sl.)			

#498 HCl good. #499 HCl fair.

Summary: Total Samples Phosphate deficiency

Class 1 - 2 - 3 - 4

16

10 5 1

Table No. 19

Results of tests on soil samples from Teton County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Trueg test P ₂ O ₅	HCl test	Correlation in field
378	J. E. Hodgkiss	Alfalfa 12 yr. ck	I	2(P+K)mod			
379	H. Hansen	Alfalfa 11 yr. ck	I	1(very)			
386	X. F. Hoeshen	Wheat	D	3(sl)			+
387	L. G. Baldwin	Alfalfa ck	I	2(mod)			+
391	J. A. Shoquist	Alfalfa ck	I	2(mod)			+
396	Savic & Larson	Wheat ck	D	1(very)			+
397	J. W. Getchell	Wheat ck	D	1(very)			
398	W. W. Cole	Alfalfa ck	I	2(mod)			+
426	John Schulz	Wheat	D	3(sl)		fair	
427	Carl Anderson	Wheat	D	3(sl)			
428	" "	Fallow	D	3(P+K)sl.			
429	John Mathison	Wheat	D	2(mod)		fair	
430	L. Fuhringer	Wheat	D	2(mod)		fair	
431	" "	Alfalfa 11 yr.	D	3(sl)		sl.	
432	S. T. Ranch	Alfalfa 20 yr.	D	3(v.sl)		good	
433	Savic & Larsen	Alfalfa PO ₄ plot	I	2(mod)		good	+
434	" "	Wheat PO ₄ plot	D	3(sl)		good	+
435	" "	Wheat ck	D	3(sl)		good	
436	" "	Wheat (NH ₃) ₃ PO ₄	D	1(very)	10	good	
437	Perry Farm	Alfalfa PO ₄ plot	I	2(mod)	50	good	
438	" "	Alfalfa ck	I	2(mod)	10+	good	
439	Malone Ranch	Native grass	sub I	2(mod)		good	
440	" "	Native grass	I	2(mod)		good	
441	" "	Native grass	sub I	1(very)		good	
442	X. F. Hoeshen	Wheat ck	D	1(very)	10	good	+
443	" " "	Wheat PO ₄ plot	D	3(sl)		good	
444	W. W. Cole	Alfalfa PO ₄ plot	I	3(sl)		good	
445	B. E. Visnant	Alfalfa PO ₄ plot	I	4(none)		good	
446	" " "	Alfalfa ck	I	3(sl)		none	- ?

Table No. 19 (continued)

Results of tests on soil samples from Teton County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Trug test P ₂ O ₅	HCl test	Correlation in field
447	J. A. Shoquist	Alfalfa 3 yr. PO ₄ plot	I	3(P+K)sl	75+	good	
448	" " "	Alfalfa ck	I	2(mod)	50	good	+
449	" " "	Potatoes ck	I	2(mod)	100	fair	
450	" " "	Potatoes PO ₄ plot	I	3(sl)		good	
451	" " "	Potatoes (NH ₃) ₃ PO ₄	I	3(v.sl)		good	
452	L. G. Baldwin	Alfalfa PO ₄ plot	I	3(sl)		fair	

#427, 428, 446 - slight acid

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

35

5 12 17 1

Table No. 20

Results of tests on soil samples from Valley County 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Corre- lation in field
389	John David	Alfalfa ck	I	4(none)			+
393	" "	Wheat ck	I	3(sl)			+
395	J. Shanbough	Alfalfa ck	I	3-(v.sl)			+

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

3

0 0 2 1

Table No. 21

Results of tests on soil samples from Wibaux County in 1931

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl test	Correlation in field
561	C. Steele	Corn	D	2(mod)	10-		
562	M. Ohnstad	Fallow	D				
563	H. Chaffie	Corn	D	3(sl)	50		
564	E. L. Watkins	Alfalfa	D	4(none)	100		
565	A. Welsh	Wheat	D	3(sl)	10+		
566	A. Barkclay	Wheat	D	3(sl)	10-		
567	J. C. Parker	Corn	D	3(sl)	75+		
568	E. A. Parker	Wheat	D	3(sl)			
569	Joe Burke	Corn	D	1(very)	25		

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

8

1 1 5 1

Table No. 22

Results of tests on soil samples from Yellowstone County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	True test P ₂ O ₅	HCl test	Correlation in field
375	B. L. Lane	Wheat	D	2(mod)			
380	S. Roberison	Wheat ck	D	3(sl)			
383	H. Johnson	Barley ck	I	3(sl)			+
384	D. Lackman, Jr.	Wheat ck	I	2(mod)			?
385	Coakley	Wheat	D	3(sl)			
461	G. Batt	Sugar beets ck	I	2(P&K)sl	150	fair	+
462	" "	Sugar beets P ₂ O ₅	I	3(sl)		fair	
500	J. D. Leaw	Potatoes	I	1(very)	150+	good	
501	C. Engle	Alfalfa ck	I	2(mod)	50+	good	+
502	H. Schatz	Alfalfa ck	I	1(very)	25+	sl	-
509	J. Kozeluh	Bean ck '30. Sugar beets	I	2(mod)		fair	+
510	" "	Sugar beets P ₂ O ₅	I	3(sl)		fair	
511	F. Siefert	Alfalfa ck	I	3(sl)		fair	+
512	" "	Sugar beets P ₂ O ₅	I	3(sl)		*	
513	" "	Sugar beets Am. P ₂ O ₅	I	2(mod)		none	
514	" "	Alfalfa P ₂ O ₅	I	3-(v.sl)		sl	
515	" "	Sugar beets ck	I	3(sl)		*	
591	W. N. Clayton	Alfalfa ck	I	2(mod)	50		-
592	" " "	Alfalfa P ₂ O ₅	I	2(mod)	75+		
593	L. Heidema	Alfalfa ck	I	2(mod)	50+		+
594	" "	Alfalfa P ₂ O ₅	I	2(mod)	50+		
595	G. Heidema	Alfalfa ck	I	2(mod)	25		+
596	" "	Alfalfa P ₂ O ₅	I	2(P&K)mod	100+		
597	P. Sherman	Alfalfa P ₂ O ₅	I	1(very)	25		-
598	H. Schatz	Alfalfa P ₂ O ₅	I	2(mod)	150		-
599	P. Pickens	Alfalfa P ₂ O ₅	I	2(mod)	75		-
600	" "	Corn ck	I	2(mod)	50+		
601	" "	Corn P ₂ O ₅	I	2(mod)	75+		

Table No. 22 (continued)

Results of tests on soil samples from Yellowstone County in 1931.

Sample No.	Name	Crop 1931	Dry or Irrig.	P ₂ O ₅ Def. Class	Truog test P ₂ O ₅	HCl Test	Correlation in field
602	J.H. Mueller	Beans ck	I	2(mod)	50		?
603	" " "	Beans P ₂ O ₅	I	3(sl)	75+		
604	" " "	Beans Am. P ₂ O ₅	I	2(mod)	75+		
605	A. O'Donnel	Alfalfa P ₂ O ₅	I	2(mod)	50+		
606	R. Stebbins	Alfalfa P ₂ O ₅	I	2(mod)	75+		
607	J. Linier	Wheat ck	I	3(sl)	25		-
608	" " "	Wheat P ₂ O ₅	I	3-(v.sl)	50+		
609	E. C. Rush	Alfalfa	I	2(mod)	100+		

* 512 slight acid. * 515 sl. acid.

Summary: Total SamplesPhosphate deficiency

Class 1 - 2 - 3 - 4

36

3 21 12 0

Table No. 23

Summary of the results of the Winogradsky test on soils collected in 1931.

County	Total Samples	Phosphate deficiency				
		Class 1	2	3	4	?
Big Horn	6	3	1	2	0	
Blaine	3	0	2	1	0	
Carbon	6	2	4	0	0	
Cascade	14	3	5	6	0	
Custer	10	5	5	0	0	
Dawson	13	0	4	9	0	
Fergus	10	0	1	8	1	
Flathead	15	1	10	4	0	
Gallatin	4	0	4	0	0	
Glacier	2	0	2	0	0	
Lake	17	0	7	8	2	
Missoula	6	5	1	0	0	
Musselshell	18	3	9	4	2	
Pondera	14	1	6	7	0	
Ravalli	11	4	4	2	1	
Richland	18	3	12	3	0	
Sanders	1	1	0	0	0	
Stillwater	16	0	10	5	1	
Teton	35	5	12	17	1	
Valley	3	0	0	2	1	
Wibaux	8	1	1	5	1	
Yellowstone	36	3	21	12	0	
	266	40	121	95	10	0
Counties	22	14	20	16	8	0

Table No. 24

Summary of the results of the Winogradsky test on soils collected in 1930.

County	Total Samples	Phosphate deficiency				
		Class 1	2	3	4	?
Big Horn	22	9	11	2	0	
Blaine	10	4	3	3	0	
Broadwater	7	2	1	0	3	1
Carbon	11	7	4	0	0	
Cascade	21	6	7	6	1	1
Fergus	12	2	3	0	7	
Flathead	1	0	1	0	0	
Gallatin	17	10	3	2	2	
Hill	21	2	5	2	12	
Judith Basin	21	3	3	9	6	
Lewis & Clark	4	2	1	0	1	
Madison	16	6	3	3	1	3
Missoula	53	19	20	6	4	4
Phillips	17	4	10	3	0	
Prairie	1	0	1	0	0	
Ravalli	30	21	3	4	1	1
Richland	1	0	0	0	1	
Roosevelt	22	7	6	5	4	
Rosebud	11	4	2	5	0	
Sanders	23	4	9	2	0	8
Sheridan	17	2	8	5	2	
Stillwater	6	1	5	0	0	
Sweet Grass	2	0	2	0	0	
Teton	21	3	11	4	3	
Toole	5	1	3	0	1	
Treasure	1	0	1	0	0	
Valley	21	0	10	7	4	
Yellowstone	84	42	32	5	5	
Totals	478	161	168	73	58	18

DISCUSSION

The most recent experimental work regarding the phosphorous deficiency of Montana soils is that being done at present by Mr. Nygard of the Chemistry Department of the Montana Agricultural Experiment Station. Mr. Nygard (13) states regarding the field trials for determining phosphate deficiency carried on during the 1930 season that the field experiments in the irrigated sections show many soils of the state to be distinctly phosphate deficient toward such important crops as alfalfa, sugar beets, and spring wheat. He further states that results from soils collected in dry-land sections of the state suggests that phosphate deficiency is not confined to the heavily cropped soils of the irrigated valleys, but it is also found in some of the regions of dry land farming.

Lyman Schenk, of the Amalgamated Sugar Company, at Missoula, Montana, reported the following in correspondence: "Practically all of the beet growers in the Bitter Root Valley used phosphate last year and the majority of them were sold on its use to the extent that they failed to leave a check plot. The growers in Flathead County are using phosphate with some very encouraging results."

According to Dr. Sackett (15) the sugar companies in Colorado and Utah are getting a 93 - 100% correlation with the Winogradsky method and field results.

The Bozeman Canning Company, of Bozeman, Montana, carried out some experiments during the summer of 1931 with regard to the effect of phosphorous on peas. Their results showed not only an increase in

yield but also an increase in the quality of the peas in the can.

Quite a number of soils were tested in 1930 from which no growth of Azotobacter was obtained. Azotobacter are not present in any number in some soils, particularly acid soils. The hydrogen ion range of Azotobacter is generally considered as being from P_H 6.65 to 7.7. Many of the soils sent to the laboratory from western Montana were acid and apparently contained no azotobacter. These fields were from "cut-over" land of forest areas which are generally acid. However, it is quite probable that other factors as well as the acidity of forest soils limit Azotobacter growth.

If soils are tested each year a good index can be obtained regarding their general condition. With proper fertilization increased yields result, thus paying for the cost of fertilization and assuring a good yearly production as far as plant food is concerned.

Several sections of Montana were known as the "bone-chewing" area, because the livestock were not getting the required amount of phosphorous from their food to supply the needs of the system, resulting in abnormal or perverted appetites and other unusual livestock disorders. Experiments were conducted by the Chemistry Department of the Montana Experiment Station (17) and resulted showed that crops grown in that area contained very little phosphorous. The application of phosphorous to the soil resulted in an increase in the phosphorous content of the crop. The increase in the phosphorous content of the crop was proportional to the increase in the yield of the crop.

The most important advantage this test offers over other phosphorous deficiency tests is the short time that is required for its completion. External factors which limit the value of the results obtained from experimental plots can easily be controlled in this laboratory procedure. The high correlation of field results with the Winogradsky test adds to its value as a soil test. A large number of samples can be tested over a short period of time in the laboratory, thus making possible the testing of many soils before the planting season, and relatively diminishing the cost of testing each sample.

SUMMARY AND CONCLUSIONS

1. The most important advantages of this test are: (a) the short time required for its completion, (b) greater control of external factors which limit the value of results obtained from field experiments (c) relative inexpense of the method, (d) a great number of samples can be tested before the planting season, (e) close correlation of the test results to field results.

2. Seven-hundred and fifty samples were tested over a two year period and 65% of them showed a phosphorous deficiency ranging from moderate to very deficient, 22% showed a slight deficiency, 10% showed no deficiency, and 3% were indeterminate.

3. The correlation of the Winogradsky test and the field results in the case of sugar beets was 95%. Soil tested from a phosphate plot after a crop of sugar beets had been removed showed a decided phosphate deficiency, indicating that the sugar beets removed a good

deal of the phosphorous applied.

4. The correlation of the Winogradsky test and field results in the case of alfalfa was 80% over the two year period. The content of phosphorous in the plant increased in proportion to the increase in yield of alfalfa.

5. The correlation of the laboratory and field results for irrigated wheat for the 1931 season was 75%. In some cases the grain on the phosphate plot matured from a week to ten days earlier than the grain on the check plot.

6. No correlation between laboratory and field results was observed in the case of beans. It appears that a good yield of beans can be obtained from a soil low in phosphorous.

7. The percentage of Montana soils deficient in potash is very low. Only one soil showed a deficiency of potash alone. Fifteen per cent of the soils showed a deficiency of potash in combination with phosphorous.

8. Many western Montana soils appear to be lacking in Azotobacter and are also acid in reaction.

9. Inoculation of a soil containing no Azotobacter by a soil known to contain many Azotobacter proved in general more satisfactory than the inoculation of the soil by a pure culture of Azotobacter.

10. Acid soils were brought to the neutral point by the addition of CaCO_3 . Neutralization of the soil plus inoculation brought positive results from previously indeterminate soils. In some cases where the soil was neutral inoculation alone gave positive results.

11. Gypsum (CaSO_4) particularly in some red soils from Sanders county produced good Azotobacter growth when used in combination with phosphorous, where phosphorous alone gave no results.

12. One hundred samples were tested by the Truog phosphorous method and no definite correlation was found between the Truog and Winogradsky methods regarding phosphorous availability. The exact reason for this lack of correlation is undetermined.

13. Sugar used in place of corn starch as a source of energy for the bacteria, produced a film over the surface of the soil plaque, making an estimation of the number and type of the bacterial growth impossible. Sugar failed to produce growth when used in a peat soil, which also did not respond to starch.

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Plate I

Small cubical box soil mixer.

This mixer consisted of a six inch cubical box made of No. 14 galvanized iron, and fitted with a screw top lid. The shaft was welded to opposite diagonal corners. The mixer was mounted on a hardwood base.

Plate II

Figure 1. Photograph of a series of soil plaques.

- A. - Check
- B. - Potash added
- C. - Phosphorous added
- D. - Potash and phosphorous added.

C and D show the nature of the *Azotobacter* growth which usually appears on the plaque.

Figure 2. Photograph of a series of soil plaques.

- A. - Check
- B. - Potash added
- C. - Phosphorous added
- D. - Potash and phosphorous added

C and D illustrate a brown or black type of *Azotobacter* growth which frequently appears in combination with the ordinary white colony development.

Plate I



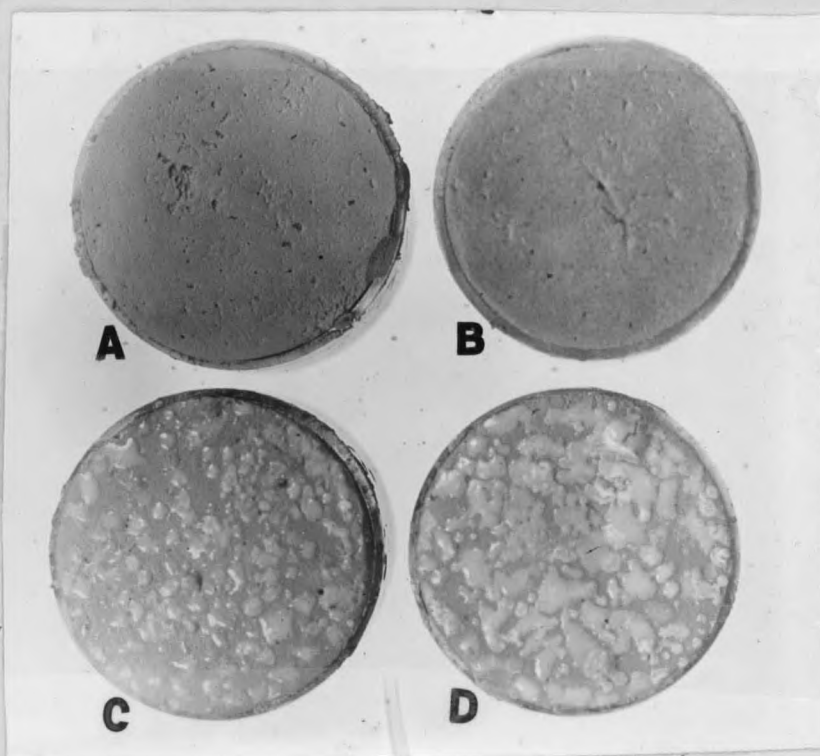


Fig. 1

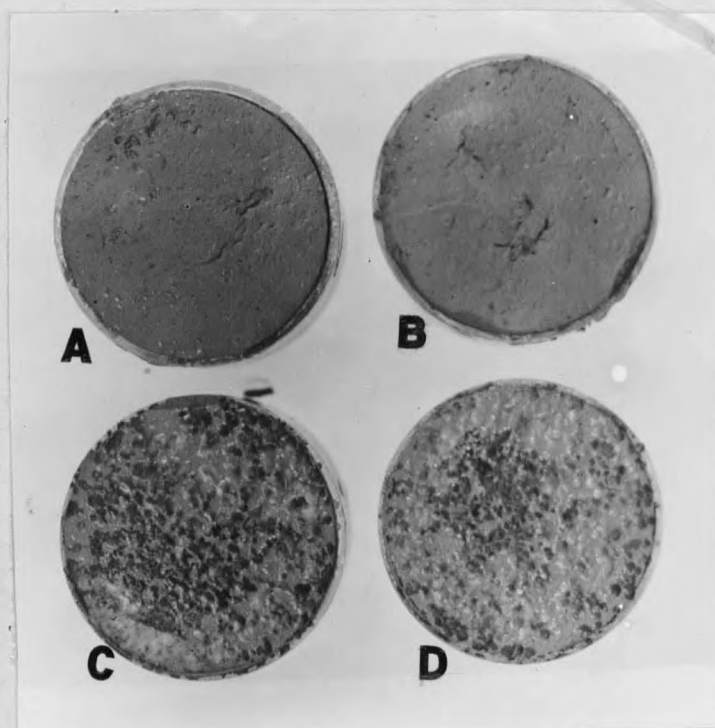


Fig. 2

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