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COMBINING FIELD FERTILIZER TRIALS WITH SOIL TESTS IN AN EFFORT TO OBTAIN THE MOST SUITABLE SOIL NITROGEN AND PHOSPHOROUS TESTS FOR SOUTHERN ALBERTA

by

Einard S. Haniuk

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Agronomy

1957

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

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INTRODUCTION

Under dryland farming operations, the use of fertilizers is often restricted due to limited crop response arising from limited seasonal moisture. Once this dryland area is brought under irrigation, there is increased use of fertilizers and increased demands for greater exactness in amounts of fertilizers to apply, due to efforts which are made to increase the returns from the land by introduction of new farming techniques and crops.

The soil tests used under dryland conditions may or may not supply the information required under the irrigated conditions and, as such, should be retested and compared with newer soil testing methods. Southern Alberta is presently in such a situation. Large tracts of land previously farmed under conditions of limited moisture are being brought under irrigation without much knowledge of fertilizer requirements under these new conditions. Here the problem is mainly concerned with the nutrients, nitrogen and phosphorous, as potassium is present in more than sufficient quantities in most cases.

The objectives of the investigation are as follows:

(1) To compare several soil tests for nitrogen and phosphorous as a means of indicating the fertilizer needs in the newly developed, irrigated regions and in the dryland areas of Southern Alberta.

(2) To provide information for a variety of crops and soils as to levels of soil fertility and likely response to added fertilizer.

Throughout the whole investigation, the following criterion for a successful soil test according to Bray (1948) and Peterson (1956) should be kept in mind.

(1) It must be fairly inexpensive.

(2) It must be fairly rapid.

(3) It must be fairly easy to perform.

(4) It must extract the total amount (or a proportionate amount) of the available form of the nutrient from soils with variable properties.

(5) It must measure with reasonable accuracy the amount of nutrient in the extract.

(6) The results should be reproducible.

REVIEW OF LITERATURE

Nitrogen

Nitrogen is a constituent of all protein and hence of all protoplasm, therefore, it is essential to the growth and reproduction of plants. Nitrate is undoubtedly the principal form taken up by the plant from the soil. Ammonia, nitrite, some of the amino acids, amides and urea have been shown to serve as suitable sources of nitrogen for one or another species of higher plants, according to Bonner and Galston (1955). The amount of each ion form taken up is partly governed by age of the plant, type of plant, soil reaction and concentration of each ion. More of the ammonia form may be taken up by seedlings than in later stages of plant growth. On the alkaline side of the pH scale ammonia is taken up in larger quantities. Ammonia and nitrite are considered toxic in larger quantities, yet Duisberg (1954) has shown that barley plants can survive concentrations of 26 p.p.m., thus showing that these ions may not be as toxic as many earlier workers have led us to believe.

The large reserves of nitrogenous compounds existing in the soil are mainly derived from the proteins synthesized by plants or by the soil organisms symbiotic and non-symbiotic. Very little is known about the actual chemical combinations in which they occur. Truog (1951) and Russell (1954) divide the nitrogenous compounds into three groups:

1. Nitrogen present as nitrate or ammonium ions, which rarely account for more than 1 percent to 2 percent of the total nitrogen present, but which forms the primary source of nitrogen for the crop. The ammonia may be held as exchangeable ions.

2. Nitrogen present in compounds that decompose fairly readily to give ammonium and/or nitrate ions often known as the nitrifiable nitro-

gen compounds.

3. Nitrogen present in compounds that are only slowly decomposed by the soil microorganisms.

The nitrate supply to the plants, according to Norman (1951) depends entirely on the pattern of release of ammonia from the organic matter during the season, and on the amount of nitrate produced in the previous season that is stored in the soil within the range of crop roots. The rate of nitrate production in the surface soil depends on the amount and nitrogen content of the readily oxidizable organic matter present, and on the actual rate of oxidation. The rate of oxidation is most rapid in moist well-aerated soil at 27° to 37° centigrade, according to Waksman and Madhok (1939), and near neutrality from work done by Chapman and Liebig (1952).

Because nearly all of the nitrogen of soils is generally associated with organic matter, rather than mineral matter, it might be expected that the pattern of availability for nitrogen would be radically different from what it is for potassium or phosphorous.

This, however, according to Norman (1951) and Truog (1951), is not the case for in order for the soil to be a frugal custodian of nitrogen, it appears necessary or desirable that the same general pattern be followed for all of the nutrient elements.

All of this released nitrogen is not used by the growing crops; many factors prevail which either make the nitrogen unavailable due to chemical combination or to complete loss from the soil. Nitrogen losses from the soil reach alarming proportions, according to Allison (1955), because of various mechanisms.

Leaching is one of the major factors in loss of nitrogen. Russell

(1954) and Chapman and Liebig (1952) present data to show the enormous losses due to leaching from all types of cropped and uncropped land.

Lysimeter studies have done much to show a clear picture of these enormous quantities of nitrogen losses from the soil.

Most workers are of the opinion that volatilization of ammonia does occur from soils. Martin and Chapman (1951) showed that in soil having a pH in excess of 7, some of the ammonia is lost by volatilization. Lowering the moisture content and raising the temperature is conducive to ammonia losses along with exchange capacity. Willis and Sturgis (1954) found that flooding is conducive to ammonia loss.

Jansson and Clark (1952) and Jones (1951) found that appreciable quantities of nitrate are lost from soil as gaseous nitrogen or that nitrite is produced. Broadbent (1951) showed that even under fully aerobic conditions, the denitrification rate was more affected by the quantity of oxidizable carbon compounds than by the amount of oxygen present.

It seems the workers Madhok and Uddin (1946) feel that losses of gaseous nitrogen from soil occur due to reaction of ammonia and nitrite ions. Allison (1955) questions the reaction and showed that nitrite reacts with alanine to form nitrogen gas under all conditions where free nitrous acid is present in appreciable amounts, but feels that this loss also is highly improbable as the soil content of nitrous acid is very low.

Ammonium and nitrate nitrogen may be rapidly immobilized in the soil in the presence of added plant material of wide C:N ratio (Broadbent and Stajonovic 1952), probably as a result of the preferential assimilation of the soluble nitrate.

Phosphorous

Phosphorous plays a fundamental role in the very large number of enzymatic reactions that depend on phosphorylation, namely the metabolism of starches, proteins and fats, according to Bonner and Galston (1955). This may be the reason it is a constituent of the cell nucleus and is essential for cell division and development of meristematic tissue.

Plants take up their phosphorous almost exclusively as inorganic phosphate ions, probably as $H_2PO_4^-$ ions. It is felt that plants can take up organic phosphates such as phytins and other inositol phosphates. Because much of the organic phosphorous in microbial tissue is in the form of nucleic acids and phosphoproteins, the immobilization of phosphorous in this form is governed by similar conditions as apply in the case of nitrogen requirements of microorganisms for protein synthesis. In some plant tissues, notably in the cereal crop residues, organic phosphorous occurs as phytin, a compound not believed to be synthesized by microorganisms. Like organic nitrogen, organic phosphorous in soil is less available than might be expected, having in mind the chemical nature of the forms concerned. Phytin appears to be precipitated in acid or alkaline soils as insoluble phytates of low solubility, as shown by Bower (1945), though phytin itself, when added to soil, may be readily decomposed. Nucleotides or nucleic acid fragments may enter into some form of combination with the clay colloids so that availability is much reduced.

It has not as yet been found possible to indicate the relationship between carbon and phosphorous that determines whether mineralization or immobilization of phosphorous may occur during the decomposition of crop residues. The phosphorous of many plant materials is in excess of microbial requirements, but because inorganic phosphorous is normally present in both soils and crops, no clear picture of the transformations which take place has been obtained. However, the use of radioactive phosphorous is helping to give us a complete picture of the transformations. Indeed, it is conceivable that the mineralization of nucleic acid phosphorous is controlled primarily by the nitrogen status of the system, and that this phase of the phosphorous cycle may be subservient to the nitrogen cycle, according to Norman (1951).

According to Dean (1938) and Pierre (1948), the phosphorous compounds of soils can be grouped into four general classes:

1. Inorganic minerals containing phosphates as an integral part of their structure. Apatite and fluoroapatite are the most widespread, but iron phosphates also occur.

2. The inorganic compounds in which the phosphorous is combined largely with calcium mainly as dicalcium phosphate, magnesium, iron as hydroxides and aluminum as oxides. There is no sharp distinction between this group and the iron and aluminum phosphate minerals for under some conditions these complexes probably crystalize out to form new minerals.

3. Organic phosphates, such as phytin and other inositol phosphates, nucleic acid and its derivatives and the other compounds that make up the humic materials.

4. The organic and inorganic phosphorous compounds in the cells of living matter, which in a sense serve as the connecting link between the other general classes of compounds.

Most work on phosphorous to date has been done on the inorganic forms. In general, solubility studies have shown that the inorganic phosphates of iron and aluminum tend to accumulate in acid soils whereas calcium phosphates are predominant in neutral or alkaline soils, according to Dean (1938) and Stelley (1943). A pH of about 6.5 to 7.0 is desirable from the standpoint of phosphorous availability because this range is above the pH of minimum solubility of iron and aluminum phosphates and below the pH of minimum solubility of calcium phosphate, as shown by Stelley (1943) in his work. Haddock (1952) working with sugar beets found that there is more phosphorous uptake with greater soil moisture. He also postulated that soil temperature and carbonic acid concentration may promote phosphorous uptake, but that high concentration of available nitrogen may hinder uptake of phosphorous. Jordan, <u>et al</u>, (1951) presents data on potatoes to substantiate Haddock's soil moisture conclusions. Evidence is also given of downward movement of soil phosphorous due to larger applications of water. There is, however, very little lateral movement of soil phosphorous.

Lewis, <u>et al</u>, (1952) found that the salts of calcium having a common ion with the soil and fertilizer phosphorous compound caused the greatest fixation of phosphorous. Calcium had the greatest effect, with magnesium less, and sodium even lower. In general, raising salt content lowered the availability of phosphorous except sodium carbonate.

Perkins and King (1944) working with 100 mesh minerals found that the mica group constitutes the chief mineral species responsible for phosphate fixation by particles in the fine sand range. In this study they found that the particle size, or surface area, presented by the iron oxides is a major factor in phosphate fixation in soils. Type of ion is also important, magnetite would not fix phosphate whereas limonite and hematite fixed considerable quantities. In other studies Perkins and King (1943) have shown that the kind of cations, position of cations in the mineral structure and amount of various cations in the mineral structure are all related to phosphate fixation. This partly explains the differences in the phosphate fixation by the iron minerals.

Phosphorous fixation studies by Coleman (1944) were carried out on kaolinite and montmorillonite clay fraction. The findings showed that the amount of phosphate fixed by clay is influenced not so much by the type of clay mineral as by the amount and activity of the free iron and aluminum oxides contained. Dalton, *et al*, (1951) has shown that this could be partly alleviated by additions of easily decomposable organic matter which is effective in making soil phosphorous more available. This is attributed to the ability of certain metabolic products of microbial decomposition to form stable complex molecules with iron and aluminum that are responsible for phosphate fixation in acid soils. Ensminger and Larson (1944) also observed there is less phosphate deficiency on land that has received liberal application of crop residues and stable manure than on land untreated with organic matter.

The importance of organic phosphorous for crop use has not been evaluated. The availability is considered to be limited, though Rogers, *et al*, (1940), Bonner and Galston (1954) have shown that some organic phosphorous may be taken up. Investigations of these factors in soils low in available phosphorous is particularly desirable.

Fuller and McGeorge (1950) have shown that calcareous Arizona soils contain rather large amounts of organic phosphorous thus disproving the previous misconception based upon the supposition that low amounts of organic phosphorous are associated with low amounts of organic matter.

This may explain why soil phosphorous tests show low available phosphorous and low organic matter, yet enough phosphorous is made available through the growing season to produce a good crop.

Most chemical tests for estimating the readily available phosphorous in soils measure only soluble inorganic phosphorous. Soils high in organic matter often give very low tests for readily available phosphorous and yet show very little response to phosphate fertilization, leading to one of two thoughts, that organic matter is helping make phosphorous available (Coleman 1944), or that organic phosphorous is important.

Soil analysis

Soil analysis by early chemists was mainly of so-called "complete soil analysis," which determined the total amounts of certain essential plant nutrients in the soil. Hopkins (1910) and others reasoned that if there was an ample amount of any element present, a sufficient quantity of it to meet the needs of large crop production would become available during the growth season. This idea would not hold and an era of partial analysis followed. Hissink (1925) was one of the many workers suggesting extraction by boiling with strong acids. Although they admitted that this treatment dissolved more of most nutrients than a crop would absorb in the current season, it was suggested that the quantities of nutrients extracted represented the amounts that would become available over a period of years. Inability to correlate the results of these methods with crop yield lead to their abandonment.

Weak acid extraction followed as a natural sequence with the thought that it would determine immediately available nutrients. These methods were partially based on findings of early workers like Dyer (1894) who felt that as the cell sap of the roots was acid, the weak acids would act like the cell sap seeping through the walls and dissolve the particles. These methods were cumbersome and hard to correlate.

Paralleling the development of the strictly chemical tests, various biological tests for nutrient elements developed. Neubauer (McGeorge (1946) developed a method using the capability of rye plants to extract phosphorous and potassium from soil as a means of measuring the available supplies of these elements in a given soil. Many other tests using pot cultures of the soil in question have also developed. These methods are used primarily as a preliminary procedure for the purpose of determining the treatment that should be tried in the field plots.

A number of methods for evaluating the nutrient status of the soil have been developed where the growth of microorganisms is used as the indicator. Such workers as Winogradsky (Dalbert 1932) and Mehlich (1934) did much in this field. On this continent, these methods involving the growth of microorganisms have not been used extensively even though they measure the nutrient status of the soil quite favorably. Here the microbiological tests have developed along another line, namely that of measuring the compounds formed as a result of microorganism's metabolism. One of the best tests to be developed along this line is the nitrate test of such Iowa workers as Fitts (1955), Hanway and Dumenil (1955), Munson (1955) and Stanford (1955). This test utilizes the method of incubating a prepared soil sample for a certain period of time, during which time the by-products of the nitrifying bacteria's metabolism gives an indication of the soil's ability to produce nitrates and the need for fertilization.

Realizing the shortcomings of the earlier soil chemists' tests, workers like Bray (1945) and Dean (1945) have given us valuable tests for potassium and phosphorous for they have determined what fraction of the soil phosphorous and potassium their tests are extracting. These, plus the improved method of extraction and determination of Bray (1940), Dickman (1940), Dean (1945), Hanway (1955) and of other workers too numerous to mention, make it possible by separate measurement and evaluation to understand the function of these various forms of nutrients in soil fertility.

As has been shown the early chemists made little progress along the lines of using chemical methods and tests to measure the fertility in a soil. The principal reasons for this lack of progress appears to have been a lack of sufficient knowledge about the chemistry of soil fertility and a strongly held, preconceived idea that the chemical method should simulate plant feeding and measure the availability of the nutrient. Bray (1948-A) challenged this preconceived idea, pointed out its faults and set up new concepts as guides for planning research to measure fertility with chemical methods.

In that paper, the concepts were discussed as follows:

> ...Usually more than one form of an element occurs in the soil at any one time. Each form contributes to a greater or lesser extent to feeding by plant roots. The significance of each form to the growth of each crop under varying conditions can be established by studies of plant growth and soil chemistry. The form or forms found to be of most significance to the immediate growth of the plant can be measured chemically and this information can serve as a partial basis for treatment recommendations.
>
> ...No attempt is made to measure the composite "availability" of all the forms of a given element present nor is the feeding power of the plant roots simulated in the extracting solution used. Instead, the extracting solutions to be used are those which can extract all of that form or forms of the element being tested for and which have, therefore, a purely chemical basis...the methods or tests must not only measure the significant forms of the elements, but also correlations must be established between the amounts of these forms of the elements present and crop response to

the fertility elements applied.

> A practical test or method is, therefore, one which has been calibrated against actual crop response under the conditions concerned...
>
> ...Such a method should measure these forms quantitatively--at least, roughly so...

Fried and Dean (1951) substantiate the statement of Bray that the plant is the final agent of the fertility measurement. They also state that the amount of the nutrient in the soil depends not only upon the soil, but also upon the specific conditions under which a given crop is grown.

In the early part of the present century the German scientist, Mitscherlich (1930), proposed to calculate the effect of different quantities of various growth factors on the yield of plants by means of a mathematical formula. The formula was based on the observation that the addition of each successive equal increment (Baule) of a given growth factor gives just one-half as much increase in crop growth as was obtained by the preceding increment.

The equation proposed by Mitscherlich to express this relationship of growth to growth factors is as follows:

$$\text{Log } (A-y) = \log A - c\ (x+b)$$

Where A = maximum yield

y = actual yield

x = quantity of a given nutrient applied

b = quantity of the given nutrient in the soil in available form

c = a proportionality constant

A mathematician, Baule, who assisted Mitscherlich with his calculations pointed out that while A represents the maximum yield obtainable with a full supply of one growth factor x for any set of conditions, consideration should be given to the maxiumu yield obtainable if all growth factors were in full supply.

This consideration is taken by Bray (1944) when he proposed this working formula:

$$\text{Log } (100-y) = \log 100 - c_1b_1$$

Where y = percent yield = $\frac{\underline{\text{yield - factor in question}}}{\text{yield all factors present}} \times 100$

b_1 = soil test result

c_1 = proportionality constant

He has confirmed this for exchangeable potassium and the adsorbed and easily-soluble forms of phosphorous for the soils in the corn belt.

Using this modified Mitscherlich formula, Arnold and Schmidt (1950) were able to obtain in 1 year a practical tentative correlation between a phosphorous test and the soil requirement of tomatoes for phosphorous.

Bray (1948) argues that this test does not apply to nitrogen, using the mobility concept as his main statement. His mobility concept is as follows:

> "The relatively mobile nutrients like nitrate nitrogen and water cannot be stored in the soil: they have no available storage form which is independent of the season."

He, however, is using in his argument the nitrate present in the soil and not the soils' ability to produce nitrate over a season. Hanway (1955) and other Iowa workers argue that the soil organic matter acts as a reserve of nitrogen for crops showing that a microbiological test which gives an indication of the rate of nitrogen release combined with fertilizer data in the Mitscherlich equation, is a useful tool in predicting the crops nitrate requirement and response. In this they are supported by the views of Norman (1951) and Truog (1951).

METHODS

Selection of Soil Test to be Used

Many tests for nitrate and phosphorous exist, each having its merits. As many methods as exist, there is always a trend governed by the popular scientific thought of the time in which direction the soil tests develop. These trends along with the need for comparison with tests now in use are the criterion for choosing the following tests.

A chemical test may give indications of nitrate deficiency, thus indicating a need for fertilizer application, yet without the fertilizer application, the microorganisms will make available nitrate in quantities sufficient for good plant growth throughout the whole season. An indication of this nitrate releasing power is given by a microbiological test which is the trend in nitrate testing. This prompted the choosing of the Iowa microbiological nitrate test developed by Hanway and Stanford (1955); results of which are successful in predicting nitrogen requirements of corn in Iowa. The strictly chemical test chosen is the nitrate test given by the U. S. Salinity Laboratory staff (1954), hereafter referred to as the "USDA #60" nitrate test. This test was selected primarily because it uses the phenoldisulfonic acid--ammonium hydroxide color development and thus would be very comparable to the Iowa test, except for the nitrification by incubation. The Spurway (1949) nitrate test using diphenylamine for color development is the test now being used in Alberta; therefore, it will be used in this study. These are the tests for the nitrate portion of the study.

In testing for phosphorous the bicarbonate extraction seems to be the trend at the moment for calcareous soils, which has prompted the choosing of the sodium bicarbonate method of Olsen (1954). The ammonium fluoride--HCl extraction of Bray and Kurtz (1945) was selected because it is more rapid than the Olsen method plus the fact that it develops the phosphorous color by use of the ammonium molybdate--tin reaction as in the Olsen method. Thus except for extraction, both tests have a common step in their procedure. The method in use at the present time in Alberta is the Spurway (1949) and it is, therefore, the third phosphorous test.

There are many more good tests available, that could have been used in the study, but limitations are necessary because of time, laboratory facilities and finances.

Individual Soil Test Procedure

To determine the nitrate content of a soil using the Spurway (1949) method, one must first obtain an "active" extract of the soil. To do this, place one-half teaspoon of soil in a graduated test tube and fill to the 13-ml. mark with distilled water. Add 1 drop of 1:3 parts acetic acid and distilled water, shake well for 1 minute and filter.

One drop of the "active" extract is put in a flat-bottomed glass vial and 8 drops of diphenylamine solution added. The color developed is compared with the nitrate color chart in the Spurway (1949) bulletin.

The Iowa method for determining soil nitrate involves the use of special glass tubes. These glass tubes have a hole in the bottom, and use one-holed rubber stoppers so that soil in the tubes would have proper circulation of air during incubation. Ten gm. of soil are mixed with an equal portion of vermiculite and placed in the glass tubes. The prepared sample is then leached with 60 ml. of distilled water. Excess water is removed from the samples by use of suction. The leachate is preserved and used for the "USDA #60" nitrate test (U. S. Salinity Laboratory 1954). The leached sample is then incubated for 2 weeks at 35 degrees centigrade. Pans of water are placed in the incubator to keep the humidity high and thus reduce evaporation from the samples. After the 2-week incubation period, the samples are again leached with 60 ml. of distilled water. This leachate is used for the Iowa nitrate (Hanway 1955) determination.

The nitrate, in both the Iowa and the USDA #60 method, is determined by the use of the phenoldisulfonic--ammonium hydroxide color development technique. The color developed is read in a photoelectric colorimeter.

In the Spurway method the phosphorous is determined using the same extract obtained for the nitrate portion of the study. To 1 ml. of the "active" soil extract in a glass tube, add 1 drop of the 5 percent sodium hydroxide solution. After shaking, add 5 drops of ammonium molybdate solution, shake again, and add a small piece of tin foil. One minute after adding the tin foil read the amount of phosphorous by comparing color developed with the prepared color chart in the Spurway (1949) bulletin.

Phosphorous, using the Olsen method, is determined by shaking together in a 125 ml. Erlenmeyer flask, 5 gm. of soil, 1 teaspoon of sodium bicarbonate-treated Darco G 60 carbon black, and 100 ml. of 0.5 molar sodium bicarbonate solution. Obtain a clear extract by filtering. Five ml. of this extract is placed in a 25 ml. volumetric flask and 5 ml. of ammonium molybdate solution added, then shaken until effervescence stops. The neck of the flask is washed down with distilled water as the volume is brought up to approximately 22 ml. One ml. of dilute stannous chloride solution is added and mixed immediately, then bring it up to volume with distilled water. The color development is read after 10 minutes using a 660 mu. filter in a photoelectric colorimeter. In preparing a standard curve, 5 ml. of 0.5 molar sodium bicarbonate solution were added to the standard phosphate solutions.

The Bray (1945) method uses 1 gm. of soil which is placed in a test tube with 7 ml. of extracting solution, and shaken for 1 minute, after which it is filtered. For each ml. of filtrate obtained, 0.05 ml. of ammonium molybdate solution is added. After shaking well, add 0.6 ml. of stannous chloride solution for every 7 ml. of filtrate. If 7 ml. of filtrate are not obtained then add a proportionate amount of the stannous chloride solution. The color developed is read after 1 minute in a photoelectric colorimeter.

Table 1. Description of soil samples used in the experiment

Soil Number	Location	Year Data Collected	Great Soil Group	Soil Texture	pH	Depth
Irrigated soils						
33	Burdett	1954, 1955	Brown	Clay loam	7.1	0-6"
34	Burdett	1954, 1955	Brown	Clay loam	7.6	0-6"
35	Burdett	1954, 1955	Brown	Silty clay loam	8.0	0-6"
39	Burdett	1954	Brown	Clay loam	7.2	0-6"
40	Burdett	1954	Brown	Clay loam	7.4	0-6"
41	Burdett	1954	Brown	Clay loam	7.9	0-6"
170	Burdett	1955	Brown	Clay loam	7.4	0-6"
172	Burdett	1955	Brown	Clay loam	7.3	0-6"
176	Burdett	1955	Brown	Clay loam	7.6	0-6"
182	Burdett	1955	Brown	Clay loam	7.9	0-6"
Dryland soils						
156	Fort Macleod	1955	Dark brown	Fine sandy loam	8.0	0-6"
158	New Dayton	1955	Dark brown	Loam	7.0	0-6"
160	Champion	1955	Dark brown	Clay loam	8.0	0-6"
162	Lethbridge	1955	Dark brown	Silty clay loam	7.4	9-6"
164	Craddock	1955	Brown	Loam	7.4	0-6"
174	Vulcan	1955	Dark brown	Loam	6.9	0-6"

Over-all methods

In order to secure data that would be representative of some parts of Southern Alberta's agricultural area, fertilizer trials were located at Burdett, Fort Macleod, New Dayton, Champion, Lethbridge, Craddock and Vulcan. The location of these sites is shown on the map in the appendix.

The description of the soils in these sites can be found in Table 1. The irrigated soils can be further described by placing them into categories in table 2.

Table 2. Further description of irrigated soils

Year	Leveling treatment		
	A	B	C
1954	33, 39	34, 40	35, 41
1955	33	34	35, 170, 172, 176, 182

A- Represents leveling where there is complete removal of surface soil.

B- Represents leveling where there is disturbance of surface soil and partial mixing with subsoil.

C- Represents leveling with little or no surface distribution.

The design of the plots on the irrigated and dryland differed because they were originally designed with other interests in mind. Both, however, lent themselves for adaptation in this investigation.

The irrigated experiments were laid out as completely randomized blocks, consisting of four rows, 21 feet long to a plot, having 9-inch spacing for grains, and 22-inch spacing for row crops. Four crops, Thatcher Wheat, Harlan Barley, Great Northern Beans and Seneca Corn, were seeded into the above plan. The fertilizer which was drilled in with the seed had the following treatment formulations:

1. Check
2. 100 pounds of 11-48-0.
3. 100 pounds of 11-48-0 plus 50 pounds of 33.5-0-0.
4. 100 pounds of 11-48-0 plus 100 pounds of 33.5-0-0.

The two types of dryland experiments were of differing design. The first was similar to the irrigated row experiment above except that there were more fertilizer treatments. There were 17 fertilizer combinations, consisting of a check, a 20-30-10 treatment, plus all possible combinations of 15, 30 and 45 pounds of P_2O_5 with 10, 20 and 40 pounds of nitrogen per acre. The source of nutrient elements for the treatment combinations came from ammonium nitrate, triple superphosphate and potassium chloride. Compana Barley and Chinook Spring Wheat were seeded with the above treatments.

The other dryland experiment was a larger one of split plot design, consisting of strips 8 feet wide and 100 feet long. There strips were fertilized with 30 and 60 pounds of nitrogen coming from ammonium nitrate, ammonium sulphate and anhydrous ammonia. Superimposed across the plots of each replication were strips of 21.5 and 43 pounds of P_2O_5 coming from triple superphosphate. Spring wheat was drilled in this experiment after the fertilizers had been broadcast on the surface of the soil.

The harvest consisted of taking 2 rod rows in the irrigated and dryland row experiments and square yard samples in the dryland split plot experiment.

All yield data were analyzed to see if response to fertilizer was significant, after which percentage yield was calculated for each crop and fertilizer element.

A representative soil sample was taken from each site before any fertilizer was added. This sample was air dried, ground to pass a 2-mm. sieve and stored in glass containers until analysis could be performed, using the tests selected in the previous section. The mechanical analysis was performed using the Bouyoucas (1951) hydrometer method. The pH of the samples was obtained from a saturated soil paste using a pH meter with a glass electrode (U. S. Salinity Laboratory Staff, 1954).

RESULTS AND DISCUSSION

The analysis of the soils used in the study are shown in Table 3. The figures in the nitrogen portion of the table represent pounds of nitrate per acre, to a depth of 6 inches, and on the phosphorous side of the table, the figures represent pounds of P per acre to a 6-inch depth, as extracted by the various soil tests. The results of the tests are also reported as pounds of nitrogen and P_2O_5 rather than nitrate and phosphorous, because the fertilizer companies report the analysis of their fertilizer products as nitrogen and P_2O_5. Each soil test gives a different value of the soil content of the particular nutrient element, for each soil test uses a different extractant whose power of extracting the nutrient element varies.

Having measured the available form or forms of the nutrient phosphorous or nitrogen in question, we had to find out what each form meant to the plant. This required the experimental data obtained in the field under conditions of which the final correlation will be applied. A simple and common measure of crop response is the increase in yield on a weight basis. However, this is not very accurate. Too many other factors besides phosphorous or nitrogen fertility, such as length of season and soil aeration, influence the actual differences between the yield of NK, PK and NPK plots. The fact that these uncontrolled factors exert a similar influence on NK, PK and NPK plots makes it logical to assume that comparison of the yields on a relative rather than absolute basis would lead to a more accurate measure of crop response. Therefore, the result of the fertilizer trials is presented in Table 4 as percent yield.

Table 3. Analysis of soils used in the study

Soil	Pounds P_2O_5 and P per acre 6 inches						Pounds N per acre 6 inches		
	Olsen		Bray		Spurway		Iowa	USDA #60	Spurway
Number	P_2O_5	P	P_2O_5	P	P_2O_5	P	N	N	N
33	69	30	46	30	18	8	31	4.1	6
34	58	26	32	14	4	2	24	1.9	6
35	43	19	3	1	9	4	14	1.5	6
39	114	50	65	29	18	8	56	0.6	9
40	96	42	86	38	2	1	40	6.8	25
41	48	21	11	5	2	1	37	1.5	5
170	61	27	106	47	18	8	80	15.2	54
172	59	26	100	44	18	8	48	3.4	18
176	61	27	93	41	2	1	39	3.4	2
182	70	31	106	47	4	2	71	7.0	1
156	45	20	2	1	2	1	39	1.9	7
158	145	64	74	33	2	1	61	4.3	6
160	111	49	132	58	9	4	39	14.4	36
162	59	26	42	28	9	4	66	3.4	6
164	76	33	42	28	2	1	38	1.5	5
174	73	32	50	22	9	4	34	1.1	2

Table 4. Percent yield of crops grown in the study

Year	Soil	Corn		Wheat		Barley	
	Number	Nitrogen	Phosphorous	Nitrogen	Phosphorous	Nitrogen	Phosphorous
1954	33	53	91	67	90	59	89
	34	34	64	64	88	63	82
	35	26	89	63	90	73	79
1954	39	96	50				
	40	81	87				
	41	56	84				
1955	33	88	77	61	84	66	89
	34	56	90	59	85	59	94
	35	63	64	58	84	55	86
	170			90	96	87	92
1955	172			77	97	79	63
	176					61	89
	182			94	98		
	156			87	71	92	65
1955	158			63	101		
	160			91	90		
	162			89	96		
	164			77	94	79	92
	174			69	91		

$$\text{For nitrogen percent yield} = \frac{\text{Yield of PK plots}}{\text{Yield of NPK plots}} \times 100$$

$$\text{For phosphorous percent yield} = \frac{\text{Yield of NK plots}}{\text{Yield of NPK plots}} \times 100$$

The study started out with four crops in the irrigated trials: beans, barley, wheat and corn. The beans and some of the corn were severely frost damaged and had to be dropped from the study as good yield data could not be obtained. The missing data of wheat and barley on some irrigated sites is due to severe hail damage preventing the taking of accurate yield data. On the dryland plots lack of time made it impossible to seed any more plots than are reported.

The forementioned data gave two values: the percent yield, y, and the soil test value, b_1, of the plot not receiving the nutrient. Bray modified the relationship that Mitscherlich and Baule found between these values and expressed it as follows:

$$\text{Log } (100-y) = \log 100 - c_1 b_1$$

Where c_1 = proportionality constant

The yield data, y, and the soil tests' results, b_1, combined in this equation yield c_1, the proportionality constant, as in the sample calculation following for nitrogen fertilizer on corn on soil number 33.

$$\text{Log } (100-y) = \log 100 - c_1 b_1$$

$$\text{Log } (100-53) = \log 100 - c_1\ 31.41$$

$$c_1 = .01044$$

The c_1 values for the rest of the crops, nutrients and soils were obtained in the same manner. All the c_1 values can be seen in Tables 5, 6 and 7.

Table 5. "c_1" values for barley on all soils for all soil tests

Soil		Nitrogen			Phosphorous		
Year	Number	Iowa	USDA #60	Spurway	Olsen	Bray	Spurway
1954	33	.0123	.0952	.0612	.0140	.0206	.0524
	34	.0182	.2275	.0850	.0112	.0236	.1627
	35	.0399	.3813	.1020	.0156	.2644	.0740
1955	33	.0149	.1152	.0740	.0140	.2064	.0524
	34	.0163	.2040	.0454	.0213	.0390	.2687
	35	.0244	.2326	.0548	.0184	.3116	.0872
1955	170	.0080	.0420	.0118	.0181	.0104	.0599
	172	.0140	.2000	.0375	.0073	.0043	.0236
	176	.0106	.1428	.1560	.0158	.0103	.5241
1955	156	.0283	.5780	.1517	.0102	.2033	.1992
	164	.0177	.4546	.1154	.0127	.0228	.5235
mean c_1 value		.0186	.2430	.0814	.0144	.0921	.1710
standard deviation		±.0092	±.1639	±.0462	±.0040	±.1197	±.1839

Table 6. "c_1" values for corn on all soils for all tests

Soil		Nitrogen			Phosphorous		
Year	Number	Iowa	USDA #60	Spurway	Olsen	Bray	Spurway
1954	33	.0145	.0806	.0518	.0152	.0225	.0571
	34	.0076	.0951	.0285	.0077	.0141	.0970
	35	.0091	.0877	.2068	.0022	.3741	.1047
1954	39	.0126	.2515	.1545	.0026	.0047	.0164
	40	.9020	.1064	.0285	.0092	.0102	.3872
	41	.0096	.2391	.0658	.0162	.0074	.4346
1955	33	.0147	.2264	.1456	.0093	.0137	.0349
	34	.0150	.1878	.0563	.0173	.0317	.2185
	35	.0152	.2895	.0682	.0102	.1731	.0485
mean c_1 value		.0115	.1738	.0989	.0100	.0724	.1554
standard deviation		±.0029	±.0818	±.0641	±.0055	±.1249	±.1568

Table 7. "c_1" values for wheat on all soils for all soil tests

Soil		Nitrogen			Phosphorous		
Year	Number	Iowa	USDA #60	Spurway	Olsen	Bray	Spurway
1954	33	.0153	.1184	.0761	.0146	.0215	.0546
	34	.0187	.2337	.0701	.0160	.0292	.2012
	35	.0307	.2948	.0650	.0230	.3902	.1093
1955	33	.0130	.1005	.0646	.0102	.0172	.0436
	34	.0163	.2040	.0612	.0142	.0261	.1800
	35	.0265	.2527	.0596	.0184	.3138	.0851
1955	170	.0126	.0659	.0184	.0230	.0132	.0764
	172	.0132	.1883	.0353	.0256	.0152	.0832
	182	.0173	.1745	.6480	.0122	.0153	.3712
1955	156	.0229	.4143	.1226	.0120	.2399	.2349
	158	.0141	.0995	.0682	.0138	.0269	.8740
	160	.0132	.0728	.0289	.0090	.0076	.1093
1955	162	.0146	.2828	.1515	.0235	.0329	.1527
	164	.0129	.4280	.1087	.0162	.0291	.6675
	174	.0149	.1563	.1876	.0178	.2079	.1143
mean c_1 value		.0171	.2060	.1180	.0166	.0924	.2238
standard deviation		±.0054	±.1136	±.1535	±.0052	±.1256	±.2404

The problem now is to select which is the best soil test from these c_1 values and their corresponding standard deviations. By looking at the tables of c_1 means it is hard to compare any of them since they differ in magnitude, thus their standard deviations are hard to compare. A common ground for comparison of the means would be the percent deviation. We can determine which soil test appears to be the most suitable by determining the probability that the magnitude of the difference between two standard deviations arises strictly from sampling errors (Treloar 1951).

The k values which are the probability that the difference between two standard deviations are strictly from sampling error were obtained as follows:

$$SE_{s_y - s_y} = \sqrt{\frac{N_x s_x^2 - N_y s_y^2}{2(N_x N_y)}}$$

$$d = s_x - s_y$$

$$k = \frac{d}{SE_{s_x - s_y}}$$

Where s_x = standard deviation of test x

s_y = standard deviation of test y

N_x = number of variates in test x

N_y = number of variates in test y

d = difference

SE = standard error of the difference $s_x - s_y$

For the comparison of the Olsen versus Bray of phosphorous on corn, using percent deviation, the value of k is as follows:

$$SE_{s_x - s_y} = \sqrt{\frac{9(54.87)^2 - 9(172.58)^2}{2\ (9X9)}}$$

$$SE_{s_x - s_y} = 42.68$$

$$ds_x - s_y = 172.58 - 54.87 = 117.71$$

$$k = \frac{117.71}{42.68} = 2.76$$

From the tables of k values given in Treloar (1951), it can be seen that the probability of a difference as large as this arising solely from errors in sampling is less than .006. The same calculation was applied to obtain all values of test comparison in Table 8 and from this it can be seen that the Olsen method for phosphorous and the Iowa method for nitrogen stand out as the most satisfactory tests.

The results of the Bray and Olsen methods were far more reproducible than were those of the Spurway method. The Spurway test uses a comparison of the unknown solution with a color chart for determining the phosphorous content rather than a photoelectric colorimeter as in the Olsen and Bray tests. Because of this, it is quite difficult to determine what amount of nutrient is in solution if the color developed lies, for instance, between the 40 ppm and the 80 ppm colored squares on the chart. The human eye is a poor judge of color depth and could easily be 10 ppm out by using this visual method.

The Spurway test required more adjustment of the volume of soil sample taken for determination, so that the extract dilution obtained would be in the proper range for reading on the chart. This comparison applied in the nitrate portion of the study as well.

More time was required to run the Iowa test because of the time taken in setting up the samples for the incubation. The incubation time, however, does not enter into the picture for it does not require that a person sit

Table 8. Probability that differences between standard deviations of two soil tests would arise solely through error of random sampling

	Soil test comparisons			
Phosphorous	Olsen vs. Bray	Olsen vs. Spurway	Bray vs. Spurway	Most Suitable Test
Corn	.006	.09	.13	Olsen
Barley	.001	.001	.53	Olsen
Wheat	.0001	.0002	.37	Olsen
Nitrogen	Iowa vs. USDA #60	Iowa vs. Spurway	Bray vs. Spurway	
Corn	.09	.02	.35	Iowa
Barley	.30	.64	.60	Iowa
Wheat	.044	.0001	.004	Iowa

and watch the samples during the incubation period. The time spent in setting up the samples for incubation may be slightly overcome by the fact that the Spurway test requires more adjustment of portion taken for extraction.

The Iowa and the Olsen tests gave more consistent c_1 values than did the other tests which is another factor in their favor.

Where the relationship expressed by the equation $\log (100-y) = \log 100 - c_1b_1$ holds, the problems of soil test correlations are greatly simplified. Theoretically, only two values are needed to establish the value of c_1 for a given rate of planting and once c_1 is found, any value of b_1 can be interpreted in terms of its percent sufficiency by letting log 100 represent the 100 percent yield where the nutrients are 100 percent sufficient, that is, adequate. This reduces all productivity levels to a common denominator, the percent yield or percent sufficiency of b_1. The c_1 value is a constant for the crop grown. Different crops may be expected to change the c_1 value.

A soil test for phosphorous or any other element indicates only the status of those nutrients. A low test may not mean that fertilizer should be used. Any practical recommendation for the use of phosphate or any other fertilizer must be based not only on the knowledge obtained from these tests, but also on knowledge concerning the favorableness of the other factors on crop growth.

The final criterion for proving that the soil tests chosen in the study are the right ones would be to set up a field fertilizer trial on the crops in the study after first obtaining suitable soil samples. Combining the soil test values for the fertilizer plots, the c_1 values for the crops in this study, and the rates of fertilizers applied in the

Mitscherlich equation, it should be possible to predict reasonably well the yield the various plots of the trials will give. If the predicted yield and the actual yield do not agree, then the tests selected in this study would be of no value.

SUMMARY

Three soil tests for phosphorous and nitrogen were combined with field fertilizer trials in order to determine the most suitable soil tests.

The soil test results and the results of the field fertilizer trials were combined in a Mitscherlich equation to obtain c_1 values. The most consistent c_1 value being an indication of the tests' adaptability for predicting the yield of plots tested by the chosen soil tests.

The Olsen test proved to be the most satisfactory test for determining phosphorous content of soils, because it gave the most consistent c_1 values, the most reproducible results, and took about the same time to perform as the other tests in the study.

The Iowa test is the most satisfactory for soil nitrate determination, for it, as did the Olsen test, gave the most consistent c_1 values, most reproducible results and, exclusive of the incubation, took very little more time to perform.

The c_1 values varied with crop and soil test.

The c_1 values for predicting yield from added phosphate fertilizer for corn is .0100, for wheat .0166 and for barley .0144, when the Olsen test is used to obtain an indication of the soil phosphorous content.

The c_1 values for predicting yield from added nitrogenous fertilizer for corn is .0115, for wheat .0172 and for barley .0186, when the Iowa test is used to obtain an indication of the soils nitrification capacity.

By combining the results of the chosen tests with the appropriate c_1 values and the quantity of fertilizer added, yield prediction for corn, wheat, and barley in Southern Alberta should be possible.

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APPENDIX

CLIMATE OF SOUTHERN ALBERTA

Southern Alberta has a north temperate, continental-type climate, but having the extremes usually present under such a climate modified due to the location of the Rocky Mountains and the prevalence of the warm, dry Chinook winds. The altitude of the test areas varied from nearly 3,500 feet above seal level at Fort Macleod to 3,000 feet at Lethbridge and 2,600 feet at Burdett.

Generally speaking, summers in Southern Alberta are characterized by slightly cooler days and considerably cooler nights than many irrigated areas in the continental United States. Mean maximum and minimum temperatures for comparison purposes are shown in Table 9 for Lethbridge and two well-known irrigated areas in the United States.

Table 9. Comparison of the monthly average daily mean maximum and mean minimum temperatures of two irrigated areas of the United States and Lethbridge, Alberta. (Hill 1953).

	Lethbridge		Fort Collins, Colo.		Salt Lake City, Utah	
Month	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
May	62.7	37.4	67.0	40.3	71.8	44.9
June	67.6	46.3	76.1	48.1	81.7	52.1
July	80.8	50.9	85.5	54.7	92.4	61.4
August	76.6	47.5	84.4	54.5	89.7	59.4
September	65.4	40.6	76.2	43.0	79.0	49.1

An indication of the length of growing season is given in the frost data summary in Table 10.

Table 10. Summary of frost data at Lethbridge Experimental Station for years 1902-1954 (inclusive). (Walker 1954).

	1954	53 year average
Last frost in spring	May 14	May 22
First frost in fall	September 29	September 15
Number of frost free days	138	116
Last killing frost in spring	May 7	May 9
First killing frost in fall	October 1	September 26
Number of crop days	147	140

Note: 1. 32° F. or less considered as frost.

2. 28° F. or less considered as killing frost.

The average precipitation at Lethbridge is approximately 16 inches, decreasing to about 13 inches at Burdett and Fort Macleod. Over the whole area, however, 75 to 80 percent of the moisture falls during the crop season. During the past 5 years the average precipitation has increased so that it is over 18 inches at Lethbridge with a proportional increase in the other test areas.

The rate of evaporation in Southern Alberta is high due to a combination of strong winds and hot summer weather.

By virtue of its northern latitude, Southern Alberta enjoys long summer days. This is a distinct advantage in agricultural production. In Table 11 the total hours of daylight (sunrise to sunset) at Lethbridge and Salt Lake City are compared.

A summary of temperature, precipitation, evaporation, wind, and hours of sunshine for the growing season are given in Table 12.

Table 11. Total hours of daylight (sunrise to sunset) at Lethbridge and Salt Lake City during the summer months.

Location	May	June	July	August	September	Total
Lethbridge	477.9	488.7	492.1	447.4	378.3	2,284.4
Salt Lake City	448.2	451.0	457.5	427.0	374.1	2,157.8

Table 12. Summary of monthly maximum, minimum and mean temperatures; precipitation, wind speed and hours of sunshine for the Experimental Station, Lethbridge, Alberta. (Walker 1954).

	May	June	July	August	September	October	Year
Temperature (°F.)							
1954 average daily maximum	63.5	65.4	78.9	71.4	63.0	56.4	51.9
53-year average daily maximum	63.8	70.5	78.8	76.7	66.0	57.3	53.4
1954 average daily minimum	38.8	44.0	49.5	49.0	41.2	30.9	29.2
53-year average daily minimum	38.1	45.7	50.2	47.8	40.1	31.7	28.6
1954 average daily mean	51.2	54.7	64.2	60.2	52.1	43.6	40.6
53-year average daily mean	51.0	58.1	64.5	62.2	53.4	44.5	41.0
1954 extreme high for month	82.5	84.5	92.5	84.5	76.5	75.0	
53-year average monthly extreme high	82.1	86.3	92.6	91.2	84.2	77.6	
1954 extreme low for month	9.0	34.0	40.0	41.0	28.5	14.5	
53-year average monthly extreme low	25.2	34.8	40.3	36.9	26.1	13.8	
Precipitation (inches)							
1954	1.12	2.16	0.77	5.02	3.70	0.08	18.03
53-year averages	2.24	2.95	1.65	1.60	1.69	0.98	16.13
Evaporation (inches							
1954	4.54	5.61	7.06	4.15	2.51	2.82	
31-year averages	4.54	4.62	6.06	5.00	3.39	2.44	
Wind (miles per hour)							
1954 monthly averages	12.4	15.1	11.6	9.5	11.0	14.2	13.9
34-year averages	12.2	10.8	9.5	9.1	10.3	12.7	12.1
Bright sunshine (daily hours)							
1954 monthly averages	8.75	8.38	12.02	8.84	7.28	7.17	6.58
46-year averages	8.31	9.20	11.02	9.65	6.98	5.50	6.44

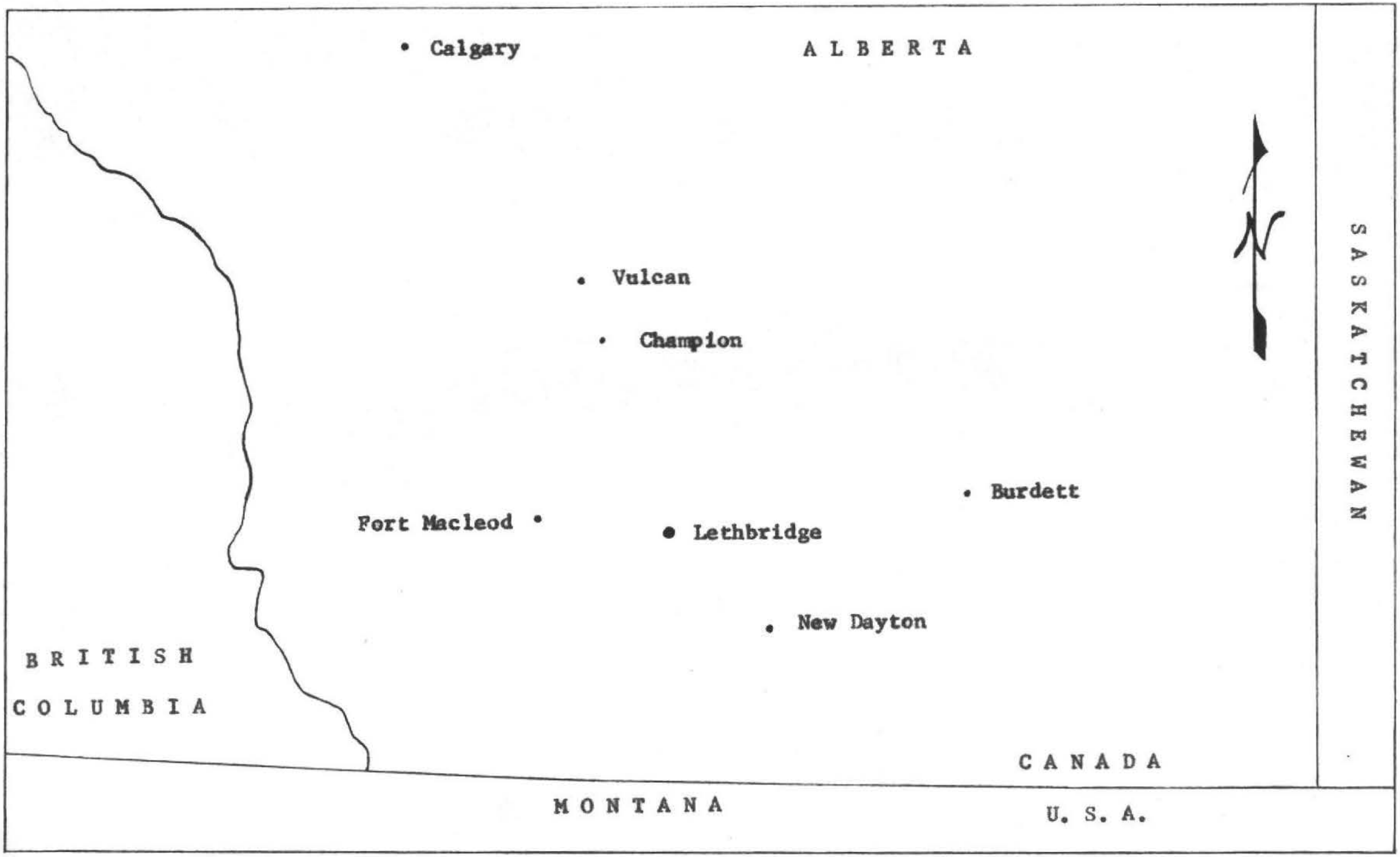

Exhibit 1. Map of Southern Alberta showing location of fertilizer trials