



The relationship between the chemical and physical properties of eight Montana soils and their response to fertilization
by Glenn P Hartman

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University
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Abstract:

A study was made of eight irrigated soils from Yellowstone and Big Horn counties of Montana that have been producing generally- unsatisfactory yields of certain crops, particularly sugar beets. The study was undertaken to obtain fundamental information as to the fertility status of these soils as indicated by their chemical and physical characteristics and the factors affecting the availability of plant nutrients.

Field fertilizer trials were conducted on each of the soils utilizing various combinations of nitrogen, phosphorus, and potassium fertilizers. Sugar beets constituted the crop grown for all tests, and data were obtained on beet yields, sugar content, and total sugar production. Various chemical and physical analyses were performed on soil samples taken from the test plot areas.

The results of the field tests indicated that nitrogen was the most deficient fertilizer element in six of the eight soils. On two of the soils, phosphorus was indicated to be the most deficient fertilizer element. No definite yield responses to potassium were obtained. In general, the lower rates of fertilizer application gave equal yield responses to that obtained with higher rates of application, Mitrdgen brought about a significant decrease in the sugar content of the beets while phosphorus and potassium had little effect in this regard. The greatest increases in total sugar yield were obtained with combinations of nitrogen and phosphorus.

The results of the chemical analysis of the soils indicated that all of the soils were slightly alkaline and contained from 0.3 to 4.4 per cent free lime, Mone of the soils contained harmful amounts of soluble salts.

The organic matter content of the soils was low and ranged from 1.6 to 2.4 per cent. The correlation between CO₂ soluble phosphorus in the soil and beet yield response to phosphorus fertilization indicated that little response was obtained when CO₂ soluble phosphorus exceeded 2,5 parts-per-million. The nitrate content of the soils, with or without incubation, was not sufficiently correlated with yield response to nitrogen to reliably predict the need of a soil for nitrogen fertilization. The organic matter content of the soils was found to be of little value in predicting the need of the soils for nitrogen fertilization. The analyses for extractable potassium indicated that all of the soils were well supplied with this element according to the standards employed in eastern United States.

The chief factors affecting phosphorus availability as measured by chemical analysis were extractable calcium and colloidal clay. An indication was obtained that the relative proportion of divalent to monovalent extractable cations also had an effect on the CO₂ soluble phosphorus content of the soil, A ratio expressing all of these factors was found to have a -0.91 correlation with the CO₂ soluble phosphorus content in the soil.

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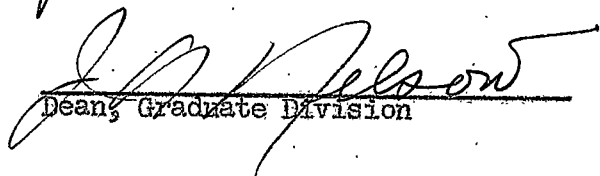
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ABSTRACT

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The results of the chemical analysis of the soils indicated that all of the soils were slightly alkaline and contained from 0.3 to 4.4 per cent free lime. None of the soils contained harmful amounts of soluble salts. The organic matter content of the soils was low and ranged from 1.6 to 2.4 per cent. The correlation between CO_2 soluble phosphorus in the soil and beet yield response to phosphorus fertilization indicated that little response was obtained when CO_2 soluble phosphorus exceeded 2.5 parts-per-million. The nitrate content of the soils, with or without incubation, was not sufficiently correlated with yield response to nitrogen to reliably predict the need of a soil for nitrogen fertilization. The organic matter content of the soils was found to be of little value in predicting the need of the soils for nitrogen fertilization. The analyses for extractable potassium indicated that all of the soils were well supplied with this element according to the standards employed in eastern United States.

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INTRODUCTION

Experimental work that has been conducted by the Montana Agricultural Experiment Station and private research organizations during the past three decades has been directed toward determining the fertility status of a wide range of Montana soils. The Experiment Station has conducted a soil testing program for farmers for many years, but these tests have been adapted from other areas with only limited evaluation of the soil tests with field fertilizer response. For the past few years, the Agronomy and Soils Department has systematically taken soil samples from field fertilizer test plots, and these are being analyzed by the Chemistry Research Department of the Montana Experiment Station in an effort to correlate soil tests with field fertilizer response. However, due to the wide variety of crops and soils being investigated, results are not yet available that could be used to predict the fertility status of soils in local areas for specific crops.

In the course of the 1950 crop season, eight fertilizer trials on irrigated sugar beets were conducted in Yellowstone and Big Horn counties by the Bureau of Plant Industry, Soils, and Agricultural Engineering of the United States Department of Agriculture cooperating with the Montana Experiment Station, the Great Western Sugar Company, and the Holly Sugar Corporation. The field tests were conducted on a cooperative basis with farmers in the area, and Dr. W. E. Larson of the Bureau of Plant Industry, Soils,

and Agricultural Engineering was in charge of the work. The purpose of the field tests was to obtain fundamental information on water relations, physical properties, and chemical properties of the soils under study as they might affect the production of sugar beets.

The selected soils upon which the field tests were conducted were quite representative of the irrigated areas in the above named counties. A wide variety of crops are grown on these soils including sugar beets, alfalfa, small grains, and beans. The cropping histories of these soils were obtainable only for the previous four or five years, but the available information indicates that they have been subjected to variable systems of field management and fertilizer practices. Fertilizer response on these soils has been quite variable, and a need for a method of evaluating their fertility status prior to fertilizer application is apparent.

Since yields and sugar content had been obtained from these sugar beet trials and soil samples had been taken, the opportunity was presented to study the chemical characteristics of these soils and to relate the results to the response to fertilizer obtained in the field. As a result, this study was undertaken with the following objectives in mind: (1) to gain fundamental knowledge as to the chemical and physical characteristics of these soils, (2) to evaluate the effect of these characteristics on the availability of soil nitrogen, phosphorus, and potassium as determined by soil analysis, and (3) to determine by soil analysis standards, the critical levels of nitrogen, phosphorus, and potassium below which crop responses to fertilizer might be anticipated.

REVIEW OF LITERATURE

The availability of soil phosphorus and its relationships to other soil factors were considered to be of paramount importance in this study since previous field tests had indicated that phosphorus is often a limiting factor in sugar beet production in Big Horn and Yellowstone counties. Preliminary tests had revealed that all of the soils were alkaline in reaction, and five of the eight soils were indicated to be calcareous by the dilute acid test. Therefore, it was considered likely that these soils would show phosphorus relationships similar to previously studied alkaline and calcareous soils of the semi-arid and arid regions.

In an investigation of calcareous soils in Idaho, Ensminger and Larson (3) found that the availability of soil phosphorus, as measured by soil analysis and crop response, declined significantly as the free lime content of the soil exceeded one per cent. According to these workers, one-half to one per cent free lime is the most favorable range for phosphorus availability since the pH of the soil within this range is not high enough to render phosphorus unavailable but is high enough to prevent phosphorus precipitation by iron and aluminum. McGeorge and Breazeale (6) consider that lime has an adverse effect on phosphorus availability through the formation of an insoluble compound of calcium carbonate and tricalcium phosphate. They have designated this compound as carbonate-phosphate, and indicate that it is composed of one mole of calcium carbonate and three moles of tricalcium phosphate.

Truog, et al., (16) consider the amount of available magnesium in the soil as an important factor in phosphorus availability and utilization

within the plant. Working with limed soils in Wisconsin, these investigators found that increasing the available magnesium content of the soil brought about a greater increase in the phosphorus content of peas than did phosphorus fertilization. Perkins (9) found that phosphorus fixation by calcium increased steadily from pH 2.5 to 9.5, but phosphorus fixation by magnesium increases to a maximum at pH 4.0 and steadily decreases thereafter to pH 9.5.

McGeorge and Breazeale (6) consider that the amount of carbon dioxide in the soil solution influences phosphorus availability through the increase in hydrogen ion brought about as carbonic acid formed. However, they consider that carbonic acid does not exist in calcareous soils except in very small quantities, and suggest that sufficient carbonic acid must be present to bring the soil pH down to 6.2--6.4 before significant amounts of phosphorus will be released in a soluble form. Additions of organic matter to the soil would seem to provide a source of carbonic acid in the soil that would benefit phosphorus availability, but these workers found that organic matter additions to calcareous soils did not materially increase phosphorus availability. Rhoads, (11) working with Nebraska soils, concluded that organic matter additions increase the available soil phosphorus principally through the phosphorus added to the soil in the decomposition of the organic matter. He also concluded that the breakdown of native soil organic matter had little influence on phosphorus availability.

Perkins (9) noted that increasing cationic concentration in solutions increased the precipitation of phosphorus. Similar effects were noted by McGeorge and Breazeale (7) who found that the presence of soluble salts in

the soil solution or extract reduced the solubility of phosphorus. Common ion calcium was considered to be quite effective in reducing phosphorus solubility by these same workers.

Another factor possibly concerned in phosphorus availability in arid region soils is the clay content of the soil. Stephenson and Chapman (15), working with California soils, noted appreciable downward movement of applied phosphates in sandy soils as a result of irrigation, but that little movement of phosphorus by water occurred in clay soils. Scarseth (14), in a study in Alabama, found that calcium saturated clay suspensions fixed considerable amounts of phosphorus above pH 7.0, but that sodium saturated clay suspensions fixed much less phosphorus within the same pH range. Similar effects were noted by Pratt and Thorne (10) in a study of calcium and sodium saturated bentonites.

The underlying factors in nitrogen availability in the soil have received considerable attention by various workers, but the complexity of the biological processes involved in ammonification and nitrification in the soil render evaluation of soil factors difficult. Soil factors considered to be of importance in the mineralization of soil nitrogen are aeration, moisture, temperature, active lime, organic matter content of the soil, and nitrogen-carbon ratio.

Allison and Sterling (1) made an extensive study of nitrate formation in slightly acid to slightly alkaline soils. They concluded that the chief factor influencing nitrate formation was the original organic matter content of the soil. A markedly beneficial effect on nitrate formation was attributed to liming these same soils. This latter factor was especially notable

in soils that were low in organic matter.

Most of the above named factors were probably reacting favorably for nitrate production during the growing season on the soils involved in this study. Possible adverse factors were low organic matter content and inadequate aeration.

Little information is available on the potassium status of semi-arid and arid region soils. One of the most extensive studies has been carried out by McGeorge (5) on calcareous soils in Arizona, in which he determined water-soluble and replaceable potassium on a large number of soils. Both types of potassium were considered to be available to plants. The results show that the soils contained from 64-765 pounds of water-soluble potassium and from 300-2130 pounds of replaceable potassium per acre foot of surface soil. McGeorge concludes that none of the soils indicate an immediate need for additional potassium, and that most Arizona soils have high reserves of available potassium.

The soils concerned in this study could be expected to show similar amounts of water-soluble and replaceable potassium as do the Arizona soils since both are developed under conditions of low rainfall and little removal of potassium by leaching. According to the standards established for the soils of eastern United States, potassium should not be deficient in soils with similar amounts of water-soluble and replaceable potassium as was found by McGeorge to occur in Arizona soils.

MATERIALS AND METHODS

The field tests upon which this study was based were carried on cooperatively with farmers in Yellowstone and Big Horn counties. Four of the tests were located in Yellowstone County and the other four in Big Horn County. Under the cooperative plan employed, the farmer prepares the field and plants the sugar beets according to his own practices. The fertilization, blocking and thinning, irrigation, and harvesting are carried out by research workers or by labor under their supervision.

The cooperating farmers, the soil types of the fields involved, and the cropping histories of the fields are listed in Table I. As the cropping histories indicate, considerable variation exists in the crops grown and the fertilizer practices employed on these soils.

The field tests were designed with eight fertilizer treatments in a randomized block design with five replications. The fertilizer treatments applied in all of the tests are listed in Table II. Nitrogen was applied in the ammonium sulphate form (20% nitrogen) at planting time, but ammonium nitrate was used as the nitrogen carrier for sidedressing. Phosphorus was applied as triple superphosphate (43% P_2O_5), and potassium was applied as muriate of potash (60% K_2O).

The individual plots were four rows wide and fifty feet long. All of the phosphate and ten pounds per acre of nitrogen were applied immediately after planting on the fields in Yellowstone County and on the Wagner field in Big Horn County. The remainder of the designated nitrogen was sidedressed during mid-June. These fields were planted flat and were not ridged.

Table I. Information on soils used for cooperative fertilizer experiments in 1950.

Cooperator	J. Propp	J. Krum	G. Reiter	S. Ewen	C. Bounous	O. Gable	T. Koyama	E. Wagner
County	Y. ^{1/}	Y.	Y.	Y.	B. H.	B. H.	B. H.	B. H.
Soil Type	Laurel clay loam	Havre sandy loam	Harlem silt loam	Laurel clay loam	Manvel silty clay	Billings silty clay	Manvel clay loam	Manvel clay loam
Past History ^{2/}								
1940-45	Alfalfa	----	----	----	Beets	----	Beets	----
1946	Beets (P)	Beans	Grain	Beets (NPM)	Beets (P)	Alfalfa	Beets	Beets
1947	Beans	Beans	Grain	Grain	Beets (P)	Alfalfa	Barley	Beets
1948	Beets (NPK)	Beans	Grain	Beets (NPK)	Beets (P)	Alfalfa	Beets (NP)	Fallow
1949	Beans (N)	Beets (P)	Grain	Beets (NPKM)	Barley	Beets (M)	Beets (NP)	Beets (P)

^{1/} Y. refers to Yellowstone County; B. H. refers to Big Horn County.

^{2/} Letters in parenthesis refer to: N = Nitrogen, P = Phosphorus, K = Potassium, M = Manure.

Table II. Fertilizer treatments used in field experiments on sugar beets.

Treatment Number	Fertilizer applied Pounds per acre		
	N	P ₂ O ₅	K ₂ O
1.	0	0	0
2.	80	0	0
3.	0	160	0
4.	80	160	0
5.	40	160	0
6.	160	160	0
7.	80	80	0
8.	80	160	80

Legend: N = Nitrogen, P₂O₅ = Phosphoric acid, K₂O = Potash

The Gable, Koyama, and Bounous fields were planted on ridges, and the fertilizer was applied after ridging but before planting. The same amounts of phosphorus, potassium, and nitrogen were applied at planting time as in the other experiments. The remainder of the designated nitrogen was side-dressed during mid-June.

The fertilizer was applied with a belt fertilizer distributor mounted on a Planet Jr. garden tractor equipped with a double disc furrow opener. In the flat planted tests, the fertilizer was applied three inches to the side of the row and four inches deep. In the ridged tests, the fertilizer was applied immediately below the row and five inches deep. Leveling of the ridges during planting reduced this depth to about three inches.

Soil samples were taken from each test area prior to planting and fertilization. The samples were taken to a depth of six inches from several locations in each replication. All samples within a replication were bulked, but the bulked samples from each replication were dried and stored separately. The samples were air dried prior to storage.

The beets were thinned and blocked by labor under the supervision of research workers in an attempt to obtain near optimum stands. The average per cent stands at harvest and the row widths are listed in Table III. A one-hundred per cent stand was considered to be a beet for every twelve inches of row.

Irrigation was also carried out under the supervision of the research workers. However, the time of irrigation was limited to the periods in which irrigation water was allotted to the farmer. The number of irrigations for each test is indicated in Table III.

Table III. General information on management of field fertilizer experiments.

Cooperator	Propp	Krum	Reiter	Ewen	Bounous	Gable	Koyama	Wagner
Type of Planting	Flat	Flat	Flat	Flat	Ridged	Ridged	Ridged	Flat
Date of Planting	4/20	5/14	4/20	4/21	4/25	4/27	4/19	4/25
Date of Thinning	6/10	6/12	6/12	6/10	6/6	6/6	6/5	
Date Sidedressed	6/16	6/18	6/17	6/15	6/21	6/20	6/19	6/19
Irrigations (Number)	5	5	4	5	5	5	5	5
Date of Harvest	9/29	9/26	9/27	9/28	10/6	10/10	10/7	10/9
Width of Rows	22"	22"	22"	22"	26"	24"	26"	22"
Per cent Stand	90	84	78	93	97	127	108	98

Gypsum resistance blocks were placed at five locations in each experiment at depths of six, twelve, twenty-four, and thirty-six inches. In addition, tensiometer data and moisture samples for gravimetric analyses were obtained from selected experiments. The purpose of this phase of the study was: (1) to aid in determining the proper time of irrigation, (2) to record the actual moisture conditions in the experiments, and (3) to determine the suitability of gypsum blocks and tensiometers under the soil and water conditions studied. Resistance readings from the blocks were obtained approximately every five days during the irrigation season. Tensiometer readings were taken every other day. The data from the moisture studies are not reported in this paper excepting as the moisture data was considered to influence the fertility status of the soils.

The yields of sugar beets were obtained by harvesting forty-five feet of row length from each of the two center rows of each plot. In the tests located in Yellowstone County, the entire plot sample was washed, tared, counted, and weighed. Two samples were taken from each plot for sugar analysis. The sugar percentage for each plot was computed as an average of two determinations. The beets from the plots harvested in Big Horn County were topped and weighed in the field. Approximately one-third of the beets were then washed and tared. Two sugar samples were taken from each plot, and the per cent sugar was determined in duplicate on each sample.

Chemical, Physical, and Mechanical Analysis of the Soil

The air dried soil samples used for the chemical analysis were coarsely ground with an iron pestle in a galvanized pail. A composite of the coarsely ground soil was obtained by bulking equal volumes of soil from

each replication of each test. The bulked samples were then ground to pass a thirty mesh seive. A porcelain mortar and pestle were used for the fine grinding. The samples were thoroughly mixed and stored in glass jars.

The pH of each soil was determined by the glass electrode method on a saturated paste of the soil. In preparing the pastes, the soil samples were weighed and the water was added from a burette so that saturation percentages for the soils could be calculated. pH readings were obtained on the pastes five minutes after preparation and again at thirty minutes after preparation. Only the thirty minute readings are reported in this paper.

The saturated pastes from the pH determinations were excluded from the air and set aside for six hours. Extracts were then taken from each sample by means of a suction pump and a Buchner funnel. Conductivity determinations were made on the extracts by means of a Solu-bridge equipped with a micro cell. Duplicate conductivity determinations were made for each soil.

Available phosphorus determinations were made in duplicate on each soil by the CO₂ extractable phosphorus method as outlined by Ensminger and Larson (3). The phosphorus was expressed as parts-per-million on an air-dry basis.

Free lime was determined on duplicate samples by the use of a Collin's calcimeter as described by Wright (17). In this method, the volume of carbon dioxide gas released from a weighed soil sample by dilute (3.0 N.) hydrochloric acid is measured in a closed system. Constant conditions of temperature are maintained by a water bath surrounding the apparatus.

Acid soluble calcium and magnesium were determined in duplicate samples

of each soil. Ten gram samples of soil were extracted by boiling thirty minutes in 100 milliliters of 1.0 N. hydrochloric acid, filtering, and making the extract up to volume. An aliquot of each sample was taken and the iron and aluminum removed by a double ammonia separation. Calcium was determined by a double precipitation with a large excess of ammonium oxalate as outlined by Koltoff and Sandell (4). The calcium was filtered in Gooch crucibles and titrated with 0.05 N. potassium permanganate. Magnesium was precipitated as magnesium ammonium phosphate and determined volumetrically according to the method of Peech (8).

Extractable cations were also determined in duplicate samples of each soil. The air dry soils were extracted by the ammonium acetate method of Peech (8). Calcium was determined volumetrically by titration with 0.05 N. potassium permanganate after a double precipitation with oxalic acid. Magnesium was determined volumetrically by the same method as was used for acid soluble magnesium. Sodium was determined gravimetrically after precipitation with uranyl magnesium acetate. Potassium was also determined gravimetrically after precipitation with sodium cobaltinitrite (8). All results were expressed on an air dry soil basis.

The rapid titration method of Peech (8) utilizing potassium dichromate was used in the analysis for soil organic matter. Duplicate samples were analyzed for each soil.

The cation exchange capacity of the soils was determined in duplicate on the same soil samples that were utilized for determining the extractable cations. After saturation with ammonium ion, the samples were washed with alcohol and the adsorbed ammonium determined by a Kjeldahl digestion.

The distillate was taken up in a four per cent solution of boric acid and titrated with standard hydrochloric acid.

The Bouyoucos hydrometer method was employed in performing mechanical analyses on the soils. After dispersion, hydrometer readings were taken both at one hour and two hour intervals to obtain both five micron and two micron clay percentages. The analyses were performed on air dry soil, but the percentages were computed on an oven dry soil basis.

Additional chemical and physical analyses were performed on some or all of the soils by Dr. W. E. Larson of the Soil Management Division of the Bureau of Plant Industry, Soils, and Agricultural Engineering.

Nitrifiable nitrogen in each of the eight soils was determined by Dr. Larson using the phenoldisulphonic acid method. In the method employed, the soil was extracted after shaking with a solution of calcium sulphate. The suspension was filtered, and aliquots were evaporated to dryness. The dried residue was treated with phenoldisulphonic acid and made alkaline with ammonium hydroxide to develop the yellow color. The intensity of the color was determined in a photoelectric colorimeter. The determinations were made on the air dry soils without incubation in the first determination. In the second determination, extracts of the same soils were analyzed after the soils had been incubated for three weeks.

In the incubation procedure, fifty grams of soil were mixed with fifty grams of white washed silica sand and placed in one pint jars. Moisture was added to bring the soil to thirty per cent moisture on the basis of the fifty gram soil sample. The jars were placed in an incubator and held at a temperature of twenty-five degrees Centigrade plus-or-minus one degree.

Once a week the jars were removed from the incubator and the moisture content of the soil was adjusted to thirty per cent if necessary. The samples were also aerated by pumping air into the bottle with a rubber bulb.

CO₂ soluble phosphorus was also determined by Dr. Larson for all of the eight soils. However, a slightly different method was employed in that a 1-5 soil-water ratio was used for making the extractions instead of the 1-10 soil-water ratio used by the author. The results obtained by the two methods were generally in agreement excepting that slightly lower values were obtained with the 1-5 soil-water ratio extract. In addition to the analysis of the surface soil samples for phosphorus, Dr. Larson determined CO₂ soluble phosphorus in the 6-12, 12-24, and the 24-36 inch depths of the Propp, Ewen, Wagner, and Koyama soils.

Utilizing a pressure membrane apparatus as described by Richards (12), Dr. Larson determined the moisture retained by each of the eight soils at 15 atmospheres tension. This point on the moisture tension curve provides an estimate of the permanent wilting percentage for each soil. The 1/3 atmosphere tension moisture percentage, which is a laboratory measure of field capacity, was also determined using a pressure plate apparatus (13).

Additional physical analyses performed by Dr. Larson include bulk density, total porosity, and the per cent of the total soil volume drained at 25 and 50 centimeters water tension. The latter values may be used as an indication of the air capacity of the soil and consequently its aeration. These analyses were performed only on the Ewen, Propp, Wagner, and Koyama soils.

Statistical Analysis of the Data

Simple correlations were employed to measure the degree of association between the various soil constituents as determined by analysis and the CO₂ soluble phosphorus content of the soils. A similar procedure was used for correlating the various values for nitrate nitrogen and other soil constituents. If a significant correlation was obtained, the assumption was made that a relationship existed between the paired values. In all such correlations, CO₂ soluble phosphorus and nitrate nitrogen were considered as dependent variables.

It was realized that the availability of phosphorus and nitrogen are probably dependent upon several soil factors acting simultaneously rather than upon one factor acting alone. In view of this, consideration was given to the use of multiple and partial correlation methods to evaluate the effect of individual soil factors in phosphorus and nitrogen availability. However, when dealing with small samples, a serious limitation exists to introducing several variables into such determinations since most or all of the variables are required to fix a regression plane leaving no information as to error.

Since the use of multiple and partial correlation did not seem to be warranted, a method was devised to evaluate the effect of soil factors in aggregate on the availability of phosphorus and nitrogen in the soil. In this method, certain soil factors were considered to influence availability negatively and other factors positively. The ratios of the products of the negative factors to the products of the positive factors were determined and correlated with CO₂ soluble phosphorus and nitrate nitrogen.

Attempts were made to fit curves to the available phosphorus--yield data by means of curvilinear regression and the Mitscherlich equation. These attempts were not successful due to the lack of data at the extremes of the available phosphorus and yield data ranges.

EXPERIMENTAL RESULTS

Field Experiments

The sugar beet yields of the individual plots, the mean per cent sugar for each fertilizer treatment, and the mean gross sugar for each fertilizer treatment of each of the eight field trials are listed in Tables IV, VIII, and IX. The analyses of variance for the yields of the individual plots are listed in Table V. The average yields of beets by fertilizer treatment for the trials in Yellowstone County are given in Table VI. Table VII gives similar information for the four trials in Big Horn County. A summary of the influence of fertilizers on yield, per cent sugar, and total sugar for all tests is given in Table X.

In six of the eight field tests, the principal yield response was obtained with nitrogen. Only the Gable and Propp fields failed to provide a yield response to nitrogen, and it is notable that these fields were the least number of years removed from alfalfa. The average yield increase obtained with nitrogen for all tests was approximately 1.6 tons per acre, with the 40 pound rate of application giving equal responses to that obtained with the 80 and 160 pound rates.

Nitrogen fertilizer produced significant decreases in the sugar content of the beets with the greatest reductions occurring with the heavier rates of nitrogen application. The average decrease in sugar content for 40, 80, and 160 pounds of nitrogen per acre were 0.18, 0.55, and 1.27 per cent respectively. However, as an average of all tests, nitrogen gave the largest increase in total sugar primarily as a result of the greater yield increases obtained with nitrogen. A tendency was noted for total sugar to

decline with increasing rates of nitrogen application. In Big Horn County, total sugar decreased 500 pounds per acre as the rate of nitrogen application was increased from 40 to 160 pounds.

The only notable yield increases from phosphorus occurred on the Propp farm in Yellowstone County and on the Gable farm in the Big Horn County. The average increase in yield from phosphorus for all tests was about 1.0 ton per acre. A considerable portion of this average increase can be accounted for by the results obtained on the Propp farm where increases in yield of about 5 tons per acre were obtained with phosphorus.

No significant effects on the sugar content of the beets were noted from applications of phosphorus. As an average of all tests, phosphorus increased the total sugar production with the greatest average increase being obtained with the 80 pound-per-acre rate of P_2O_5 . However, the trends for individual tests were variable, and the higher rates of application provided the greatest increases in total sugar in certain trials.

The only yield increase from potassium application was obtained in the Krum test in Yellowstone County, but an examination of the data creates some doubt as to whether an increase in yield from potassium actually occurred in this test. Treatment No. 7, containing only nitrogen and phosphorus, gave nearly as high an average yield as did the potassium treatment although comparable yield increases were not obtained from other nitrogen and phosphorus treatments. Thus, it appears that the apparent response to potassium might have resulted from soil variability or other experimental error.

As an average of all tests, potassium had little or no effect on the sugar content of the beets, but it did provide an increase of 195 pounds per acre of total sugar.

Table IV. Plots yields of sugar beets from cooperative field trials.

Propp Plots

Treatment			Sample Yield--Tons/acre per Plot					Total	Ave.
N	P ₂ O ₅	K ₂ O	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	6.77	9.04	10.31	10.64	13.05	49.81	10.0
80	0	0	7.06	9.35	8.92	12.50	12.37	50.20	10.0
0	160	0	14.26	15.79	14.94	15.66	14.85	75.50	15.1**
80	160	0	15.47	13.70	15.47	13.28	15.60	73.52	14.7**
40	160	0	15.06	20.21	14.60	16.10	15.91	81.88	16.4**
160	160	0	16.63	16.98	15.46	16.47	13.28	78.82	15.8**
80	80	0	16.31	15.13	14.43	15.52	15.79	77.18	15.4**
80	160	80	15.87	14.47	14.72	16.75	17.26	79.07	15.8**

L.S.D. at 5% level -- 2.12 tons/acre

L.S.D. at 1% level -- 2.83 tons/acre

** Indicates a significant increase over unfertilized treatment at 1% level.

Krum Plots

Treatment			Sample Yield--Tons/acre per Plot					Total	Ave.
N	P ₂ O ₅	K ₂ O	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	16.00	15.26	14.65	14.51	12.49	72.91	14.6
80	0	0	18.20	18.37	16.05	15.17	14.72	82.51	16.5**
0	160	0	14.82	15.44	14.41	15.07	13.77	73.51	14.7
80	160	0	16.26	16.00	16.94	15.03	13.54	77.77	15.6
40	160	0	18.03	16.01	15.10	15.47	14.77	79.38	15.9*
160	160	0	18.33	17.04	15.72	16.58	12.32	79.99	16.0*
80	80	0	21.15	18.15	15.28	16.95	17.19	88.72	17.7**
80	160	80	19.22	18.73	17.94	16.92	17.65	90.46	18.1**

L.S.D. at 5% level -- 1.30 tons/acre

L.S.D. at 1% level -- 1.77 tons/acre

* Indicates a significant increase over unfertilized treatment at 5% level.

** Indicates a significant increase over unfertilized treatment at 1% level.

Table IV. (continued)

Reiter Plots

Treatment			Sample Yield--Tons/acre per Plot					Total	Ave.
N	P ₂ O ₅	K ₂ O	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	13.69	13.62	13.02	14.49	17.13	71.95	14.4
80	0	0	16.49	16.22	17.62	16.95	17.44	84.72	16.9*
0	160	0	11.76	12.68	16.37	18.07	12.55	71.43	14.3
80	160	0	13.20	16.32	17.17	18.32	18.51	83.52	16.7*
40	160	0	18.77	14.61	12.47	17.21	18.07	81.13	16.2
160	160	0	16.08	15.63	18.60	18.14	20.18	88.63	17.7*
80	80	0	15.26	17.11	15.79	18.62	18.64	85.42	17.1*
80	160	80	15.10	16.80	17.83	17.54	17.54	84.81	17.0*

L.S.D. at 5% level → 2.11 tons/acre

L.S.D. at 1% level → Not significant

* Indicates a significant increase over unfertilized treatment at 5% level.

Ewen Plots

Treatment			Sample Yield--Tons/acre per Plot					Total	Ave.
N	P ₂ O ₅	K ₂ O	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	12.90	8.50	9.40	11.35	12.99	55.14	11.0
80	0	0	13.74	(13.56)	13.94	14.61	14.55	70.40	14.1**
0	160	0	12.12	12.94	11.73	13.16	10.92	60.87	12.2
80	160	0	15.71	14.76	15.66	16.12	14.06	76.31	15.3**
40	160	0	13.07	13.98	13.19	13.65	13.40	67.29	13.5**
160	160	0	15.15	14.34	14.52	15.54	14.59	74.14	14.8**
80	80	0	13.23	15.22	15.80	14.16	14.24	72.65	14.5**
80	160	80	15.17	12.71	15.10	16.32	14.70	74.00	14.8**

L.S.D. at 5% level → 1.74 tons/acre

L.S.D. at 1% level → 2.34 tons/acre

** Indicates a significant increase over unfertilized treatment at 1% level.

() Denotes missing plot

Table IV. (continued)

Bouncy Plots

N	P ₂ O ₅	K ₂ O	Sample Yield--Tons/acre per Plot					Total	Ave.
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	20.10	15.98	16.32	15.78	19.12	87.32	17.5
80	0	0	18.85	17.89	17.92	(17.63)	18.31	90.60	18.1
0	160	0	16.03	18.81	15.34	(15.66)	15.25	81.09	16.2
80	160	0	17.25	19.59	18.69	20.92	19.54	95.99	19.2
40	160	0	23.86	20.71	19.74	21.04	17.72	103.07	20.6**
160	160	0	16.36	19.41	20.03	16.62	19.09	91.51	18.3
80	80	0	19.18	18.28	19.00	17.66	16.89	91.01	18.2
80	160	80	19.76	20.06	20.31	18.13	20.66	98.92	19.8*

L.S.D. at 5% level -- 2.07 tons/acre

L.S.D. at 1% level -- 2.80 tons/acre

* Indicates a significant increase over unfertilized treatment at 5% level.

**Indicates a significant increase over unfertilized treatment at 1% level.

Gable Plots

N	P ₂ O ₅	K ₂ O	Sample Yield--Tons/acre per Plot					Total	Ave.
			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	17.92	16.60	17.51	15.60	15.26	82.89	16.6
80	0	0	17.16	17.92	17.77	17.58	16.72	87.15	17.4
0	160	0	(18.97)	19.23	19.20	16.30	17.85	91.55	18.3*
80	160	0	18.90	16.85	17.68	18.09	18.60	90.12	18.0*
40	160	0	17.76	18.66	17.78	17.87	17.93	90.00	18.0*
160	160	0	17.66	15.97	17.76	17.72	16.86	85.97	17.2
80	80	0	18.52	17.22	17.95	17.57	17.75	89.01	17.8*
80	160	80	20.55	19.40	16.35	18.03	19.32	93.65	18.7*

L.S.D. at 5% level -- 1.22 tons/acre

L.S.D. at 1% level -- Not significant

* Indicates a significant increase over unfertilized treatment at 5% level.

() Denotes missing plot.

Table IV. (concluded)

Koyama Plots

Treatment			Sample Yield--Tons/acre per Plot					Total	Ave.
N	P ₂ O ₅	K ₂ O	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	14.59	16.87	15.72	15.80	13.79	76.77	15.4
80	0	0	18.01	13.36	16.84	17.59	16.97	82.77	16.6
0	160	0	14.20	15.32	15.40	14.31	15.32	74.55	14.9
80	160	0	15.44	17.84	16.99	15.08	16.20	81.55	16.3
40	160	0	14.92	17.04	18.63	18.45	16.63	85.67	17.1*
160	160	0	16.45	18.81	15.44	14.62	17.49	82.81	16.6
80	80	0	15.84	18.37	17.68	15.65	15.53	83.07	16.6
80	160	80	17.31	15.58	15.38	17.73	16.33	82.33	16.5

L.S.D. at 5% level -- 1.5 tons/acre

L.S.D. at 1% level -- Not significant

* Indicates a significant increase over unfertilized treatment at 5% level.

Wagner Plots

Treatment			Sample Yield--Tons/acre per Plot					Total	Ave.
N	P ₂ O ₅	K ₂ O	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
0	0	0	12.64	13.15	13.50	12.80	13.21	65.30	13.1
80	0	0	13.05	13.70	14.67	13.43	14.12	68.97	13.8
0	160	0	12.82	14.18	12.29	13.52	12.81	65.62	13.1
80	160	0	14.07	14.58	13.44	15.25	14.13	71.47	14.3**
40	160	0	14.25	14.18	13.73	14.55	14.68	71.39	14.3**
160	160	0	13.55	14.30	14.51	15.15	13.24	70.75	14.2**
80	80	0	14.04	13.58	14.56	13.53	14.68	70.39	14.1**
80	160	80	14.84	13.88	14.13	14.66	13.77	71.28	14.3**

L.S.D. at 5% level -- 0.77 tons/acre

L.S.D. at 1% level -- 1.04 tons/acre

** Indicates a significant increase over unfertilized treatment at 1% level.

Table V. Analysis of variance data for yields of sugar beets.

Propp Plots

Variation due to	D.F.	Mean Square	F value
Replications	4	2.88	1.08
Treatments	7	34.02	12.60**
Error	28	2.68	
Total	39		

** Significant at 1% level

Krum Plots

Variation due to	D.F.	Mean Square	F value
Replications	4	11.94	11.82**
Treatments	7	8.17	8.09**
Error	28	1.01	
Total	39		

** Significant at 1% level

Reiter Plots

Variation due to	D.F.	Mean Square	F value
Replications	4	10.36	3.82*
Treatments	7	8.12	3.00*
Error	28	2.71	
Total	39		

* Significant at 5% level

Table V. (continued)

Ewen Plots

Variation due to	D.F.	Mean Square	F value
Replications	4	0.64	0.34
Treatments	7	12.06	6.46**
Error	27	1.86	
Total	38		

** Significant at 1% level

Bounous Plots

Variation due to	D.F.	Mean Square	F value
Replications	4	1.31	0.51
Treatments	7	9.40	3.67**
Error	26	2.56	
Total	37		

** significant at 1% level

Gable Plots

Variation due to	D.F.	Mean Square	F value
Replications	4	1.34	1.50
Treatments	7	2.29	2.57*
Error	27	0.89	
Total	38		

* Significant at 5% level

Table V. (concluded)

Koyama Plots

Variation due to	D.F.	Mean Square	F value
Treatments	7	2.99	2.09*
Error	27	1.43	
Treatment + Error $\frac{1}{2}$	34		

* Significant at 5% level

$\frac{1}{2}$ Analysis of covariance employed with this trial.

Wagner Plots

Variation due to	D.F.	Mean Square	F value
Replications	4	0.22	0.61
Treatments	7	1.31	3.66**
Error	28	0.36	
Total	39		

** Significant at 1% level

Table VI. Summary of influence of fertilizers on the yield of sugar beets in Yellowstone County.

			Prepp		Krum		Reiter		Ewen		Average	
			Tons/Acre		Tons/Acre		Tons/Acre		Tons/Acre		Tons/Acre	
Treatment			Ave.	Incr. over	Ave.	Incr. over	Ave.	Incr. over	Ave.	Incr. over	Ave.	Incr. over
N	P ₂ O ₅	K ₂ O	Yield	Check	Yield	Check	Yield	Check	Yield	Check	Yield	Check
0	0	0	10.0	---	14.6	---	14.4	---	11.0	---	12.5	---
80	0	0	10.0	0.0	16.5	1.9	16.9	2.5	14.1	3.1	14.4	1.9
0	160	0	15.1	5.1	14.7	0.1	14.3	-0.1	12.2	1.2	14.1	1.6
80	160	0	14.7	4.7	15.6	1.0	16.7	2.3	15.3	4.3	15.6	3.1
40	160	0	16.4	6.4	15.9	1.3	16.2	1.8	13.5	2.5	15.5	3.0
160	160	0	15.8	5.8	16.0	1.4	17.7	3.3	14.8	3.8	16.1	3.6
80	80	0	15.4	5.4	17.7	3.1	17.1	2.7	14.5	3.5	16.2	3.7
80	160	80	15.8	5.8	18.1	3.5	17.0	2.6	14.8	3.8	16.4	3.9
L.S.D. (5%) ^{1/}			2.1		1.3		2.1		1.7			
L.S.D. (1%)			2.8		1.8		---		2.3			
C.V. (%) ^{2/}			11.6		6.2		10.1		9.6			

^{1/} Least Significant Difference

^{2/} Coefficient of Variability

Table VII. Summary of influence of fertilizers on the yield of sugar beets in Big Horn County.

Treatment			Bounous		Gable		Koyama		Wagner		Average	
			Tons/Acre		Tons/Acre		Tons/Acre		Tons/Acre		Tons/Acre	
N	P ₂ O ₅	K ₂ O	Ave. Yield	Incr. over Check	Ave. Yield	Incr. over Check	Ave. Yield	Incr. over Check	Ave. Yield	Incr. over Check	Ave. Yield	Incr. over Check
0	0	0	17.5	—	16.6	—	14.6	—	13.1	—	15.4	—
80	0	0	18.1	0.6	17.4	0.8	16.5	1.9	13.8	0.7	16.4	1.0
0	160	0	16.2	-1.3	18.3	1.7	14.9	0.3	13.1	0.0	15.6	0.2
80	160	0	19.2	1.7	18.0	1.4	16.8	2.2	14.3	1.2	17.1	1.7
40	160	0	20.6	3.1	18.0	1.4	16.6	2.0	14.3	1.2	17.4	2.0
160	160	0	18.3	1.8	17.2	0.6	17.1	2.5	14.2	1.1	16.7	1.3
80	80	0	18.2	0.7	17.8	1.2	16.5	1.9	14.1	1.0	16.6	1.2
80	160	80	19.8	2.3	18.7	2.1	16.9	2.3	14.3	1.2	17.4	2.0

L.S.D. (5%) ^{1/} 2.1 1.2 1.5 0.8

L.S.D. (1%) 2.8 — — 1.0

C.V. (%) ^{2/} 8.6 5.4 7.4 4.3

^{1/} Least Significant Difference

^{2/} Coefficient of Variability

35

Table VIII. The influence of commercial fertilizers on the per cent sugar in sugar beet roots.

Treatment			Per cent Sugar Yellowstone County				Per cent Sugar Big Horn County				Diff. from check	
N	P ₂ O ₅	K ₂ O	Propp	Krum	Reiter	Ewen	Bounous	Gable	Koyama	Wagner		Ave.
0	0	0	16.8	17.7	16.7	17.1	16.9	17.7	16.2	16.6	17.0	—
80	0	0	16.3	16.7	16.2	17.0	16.7	17.0	15.8	16.0	16.5	-0.5
0	160	0	17.2	17.4	16.5	17.0	17.1	17.4	16.7	16.4	17.0	0.0
80	160	0	16.1	17.0	16.1	16.9	16.3	17.2	15.8	15.9	16.4	-0.6
40	160	0	16.6	17.5	16.3	17.3	16.6	17.5	16.1	16.4	16.8	-0.2
160	160	0	15.4	16.0	15.4	16.1	15.9	16.3	15.4	15.1	15.7	-1.3
80	80	0	16.2	17.0	16.3	16.8	16.5	17.1	15.9	16.2	16.5	-0.5
80	160	80	15.9	17.0	16.2	17.1	15.8	17.3	16.1	16.1	16.4	-0.6

L.S.D. (5%) ^{1/} 0.7 0.5 0.5 0.4 0.4 0.5 — 0.7

L.S.D. (1%) 1.0 0.7 0.6 0.5 0.6 0.7 — 0.9

C.V. (%) ^{2/} 4.0 2.4 2.1 1.8 2.0 2.2 5.1 2.4

^{1/} Least Significant Difference

^{2/} Coefficient of Variability

Table IX. The influence of commercial fertilizers on the total sugar production of sugar beets.

Treatment	Total Sugar--Pounds per acre											Diff. from Check
	N	P ₂ O ₅	K ₂ O	Propp	Krum	Reiter	Ewen	Boumou	Gable	Koyama	Wagner	
0	0	0	3350	5160	4810	3770	5890	5860	4730	4370	4740	---
80	0	0	3280	5510	5480	4770	5990	5910	5210	4420	5070	330
0	160	0	5190	5120	4730	4130	5550	6370	4980	4300	5050	310
80	160	0	4740	5270	5380	5150	6260	6210	5310	4550	5360	620
40	160	0	5440	5560	5310	4640	6830	6280	5340	4690	5510	770
160	160	0	4870	5440	5470	4790	5830	5600	5420	4260	5170	430
80	80	0	5020	6040	5580	4890	5990	6080	5250	4570	5430	690
80	160	80	5020	6140	5480	5060	6260	6460	5440	4580	5550	810

L.S.D. (5%) ^{1/}	870	440	N.S. ^{3/}	470	310	410	N.S.	270
L.S.D. (1%)	1170	590	N.S.	630	N.S.	830	N.S.	N.S.
C.V. (%)	14.6	6.1		7.9	8.6	5.8		4.6

^{1/} Least Significant Difference

^{2/} Coefficient of Variability

^{3/} Not Significant

Table X. Summary of influence of commercial fertilizers on sugar beets.

Treatment lbs. per Acre	Yellowstone County			Big Horn County			Average		
	Yield T./A.	Sugar %	Sugar lbs.	Yield T./A.	Sugar %	Sugar lbs.	Yield T./A.	Sugar %	Sugar lbs.
Nitrogen (N)									
40	1.4	-0.10	445	1.8	-0.25	480	1.6	-0.18	465
80	1.5	-0.50	345	1.5	-0.60	280	1.5	-0.55	313
160	2.0	-1.30	280	1.1	-1.23	-20	1.6	-1.27	130
Phosphorus (P ₂ O ₅)									
80	1.8	0.03	620	0.2	0.05	90	1.0	0.04	355
160	1.2	-0.03	375	0.7	-0.07	200	1.0	-0.05	288
Potassium (K ₂ O)									
0.8	0.8	0.03	290	0.3	0.02	100	0.6	0.02	195

From the water relations observations made on these fields, Dr. Larson concluded that the resistance of gypsum blocks gave a good indication of the moisture in the soil when the moisture is well below the field capacity. At or near the field capacity, the blocks are not very sensitive to soil moisture changes. Soluble salts did not appear to greatly affect the resistance readings at the 6 or 12 inch depths. At greater depths, the resistance readings were often below those obtained in water suggesting that soluble salts existed in sufficient concentration as to affect the resistance readings.

Dr. Larson also found that tensiometers, in contrast to gypsum blocks, had their greatest usefulness at moisture contents near the field capacity. Data from the tensiometer readings taken on the Propp field indicated that moisture tension was held near field capacity on this field during most of the irrigation season.

Results of Chemical and Physical Analyses of the Soil

The data obtained in the chemical and physical analyses of the soils are listed in Tables XI - XVI. The individual values are averages of duplicate determinations for all analyses which were performed in duplicate.

The analyses indicate that the soils are normal semi-arid region soils in regard to pH with all soils showing a slightly alkaline reaction. None of the soils are indicated to contain sufficient soluble salts to be harmful to the growth of sugar beets. However, the Gable soil may contain sufficient salt to be detrimental to the growth of less salt tolerant crops.

A considerable range was noted in the CO_2 soluble phosphorus present

Table XI. Data on CO₂ soluble phosphorus, conductivity, and pH.

SOIL	DEPTH Inches	CO ₂ Extr. PHOSPHORUS 1--10 Soil- Water ratio P.p.m. <u>1/</u>	CO ₂ Extr. PHOSPHORUS 1--5 Soil- Water ratio P.p.m.	CONDUCTIVITY K X 10 ⁻⁵	pH
Krum	0-6	11.50	8.3	124	7.65
Reiter	0-6	7.25	3.2	108	7.35
Bounous	0-6	2.20	1.0	138	7.62
Gable	0-6	1.40	0.8	241	7.65
Propp	0-6	1.25	0.7	98	7.45
	6-12		0.3	50	7.72
	12-24		0.6	60	7.90
	24-36		0.7	80	8.02
Ewen	0-6	18.75	16.6	178	7.52
	6-12		5.8	172	7.82
	12-24		3.9	210	7.90
	24-36		2.1	220	8.00
Wagner	0-6	1.90	1.2	128	7.68
	6-12		0.7	100	7.78
	12-24		0.4	110	8.00
	24-36		0.4	110	8.00
Koyama	0-6	3.25	1.8	172	7.66
	6-12		0.6	128	7.75
	12-24		0.4	170	7.78

1/ Parts-per-million.

in these soils. Individual values ranged from 1.25 parts-per-million phosphorus to 18.75 parts-per-million phosphorus with the Propp and Ewen soils showing these values respectively. All of the soils except the Ewen, Krum, and Reiter soils would be classified as being low in available phosphorus according to the standards now employed by the Chemistry Research Department of the Montana Experiment Station.

While none of the soils are excessively high in their content of free lime, five of the eight soils would fall into the category of having more than one per cent free lime. Phosphorus availability is likely to be depressed when free lime exceeds one per cent of the total weight of the soil according to Ensminger and Larson (3).

The relative amounts of acid soluble calcium in each of these soils follow closely the trend indicated by the free lime content. Soils high in lime tend to be high in acid soluble calcium, and soils low in free lime tend to be low in acid soluble calcium. The amounts of acid soluble magnesium extracted were surprisingly high and bore little relation to the free lime content of the soil. In some soils, the acid soluble magnesium actually exceeded the acid soluble calcium on a milliequivalent basis.

Extractable calcium was high in all soils and in the case of certain soils, actually exceeded the cation exchange capacity of the soil. Thus, it appears certain that a considerable portion of the extractable calcium was provided by soluble salts, gypsum, or lime in the soil. Gypsum is appreciably soluble in neutral normal ammonium acetate which was employed as the soil extracting reagent. However, it is believed that the amounts of lime dissolved in the extraction were very small and that the calcium

Table XII. Chemical analysis of soils for acid soluble and extractable cations.

Soil	Cations Extracted With 1.0 N. HCl				Cations Extracted With Ammonium Acetate			
	Calcium		Magnesium		Milliequivalents per 100 grams			
	Per cent	M.E./100 gr. ^{1/}	Per cent	M.E./100 gr.	Ca	Mg	Na	K
Ewen	0.54	26.83	0.602	49.52	21.0	9.06	0.81	1.79
Krum	1.38	69.18	0.692	56.92	28.5	4.08	0.70	1.18
Reiter	0.48	23.82	0.484	39.89	15.2	7.43	0.56	1.37
Koyama	1.91	95.48	0.996	81.89	41.4	7.32	1.61	1.03
Bounous	1.10	55.15	0.675	55.50	37.4	9.10	1.63	1.45
Wagner	2.35	117.71	0.990	81.44	38.1	7.57	0.90	0.82
Gable	1.68	83.91	0.887	72.92	40.3	8.99	2.32	1.66
Propp	0.73	36.35	0.626	51.52	27.1	9.33	0.54	1.04

^{1/} Milliequivalents per 100 grams of air dry soil.

Note: The soils are arranged in decreasing order of their CO₂ phosphorus content.

extracted by this procedure represents that which would be active in the soil.

None of the soils were deficient in available potassium as measured by the chemical analysis. The values obtained for individual soils indicate a range of extractable potassium in these soils of from 640 to 1400 pounds per acre furrow slice. The amount of extractable sodium was indicated by the analysis to be low for all of the soils.

Nitrate nitrogen prior to incubation was found to range from 8.6 to 49.7 parts-per-million in these soils. Upon incubation, moderate increases in the amounts of nitrate nitrogen were found to occur in all of the soils. The range in nitrifiable nitrogen values was not great with all of the soils falling within a range of twenty-five parts-per-million.

All of the soils were low in organic matter. The soils were remarkably similar in their organic matter content with the range between the highest and lowest values being only 0.76 per cent.

The mechanical analysis revealed that all of the soils were heavy in texture with the exception of the Krum soil which was found to be a sandy loam. The exchange capacities of the soils were closely correlated with the two micron clay content as would be expected in soils that are low in organic matter.

The subsoil analyses for available phosphorus on the Propp, Wagner, Ewen, and Koyama samples indicated that the available phosphorus decreases with depth. However, the Ewen soil which has a high content of available phosphorus in the surface layers, also has a rather high content of available phosphorus to a depth of twenty-four to thirty-six inches.

Table XIII. Chemical analysis of soils for exchange capacity, free lime, organic matter, and nitrates.

Soil	Exchange Capacity M.E. per 100 grams	Free Lime Per cent	Organic Matter Per cent	Nitrates		Diff.
				Parts-per-million		
				Before Incubation	After Incubation	
Ewen	22.87	0.32	2.18	24.6	79.5	54.9
Krum	13.89	2.17	1.73	12.3	83.1	70.7
Reiter	23.00	0.43	2.05	25.3	107.5	82.2
Koyama	23.55	3.65	1.60	28.6	81.8	63.2
Bounous	31.70	1.90	1.79	25.0	89.5	64.5
Wagner	20.99	4.44	1.61	8.6	69.7	71.1
Gable	33.24	3.08	2.36	49.7	120.0	70.3
Propp	28.32	0.63	2.16	38.6	114.0	75.4

Note: The soils are arranged in decreasing order of their CO₂ phosphorus content.

Table XIV. Mechanical analysis of soils.

Soil	Mechanical Composition - Per cent ^{1/}				Texture
	Sand	Silt	5 micron Clay	2 micron Clay	
Ewen	34.7	35.8	34.2	29.4	Clay Loam
Krum	57.6	31.5	13.0	10.9	Sandy Loam
Reiter	24.1	50.7	31.2	25.2	Silt Loam
Koyama	21.2	46.4	37.8	32.4	Clay Loam
Bounous	15.2	40.2	51.3	44.6	Silty Clay
Wagner	23.6	46.2	34.6	30.2	Clay Loam
Gable	12.5	44.8	48.7	42.6	Silty Clay
Propp	20.7	49.7	33.4	29.6	Clay Loam

^{1/} Based on the oven-dry weight of the soil.

Note: The soils are arranged in decreasing order of their CO₂ phosphorus content.

Table XV. Moisture tension determinations on soils.

Soil	Saturation Percentage	Per cent Moisture Held At:	
		1/3 Atmos. Tension	15 Atmos. Tension
Ewen	46.7	28.8	13.8
Krum	30.3	17.4	7.3
Reiter	46.1	31.3	12.9
Koyama	54.9	31.7	15.7
Bounous	55.0	32.2	17.4
Wagner	49.6	29.3	14.0
Gable	60.2	35.8	20.1
Propp	53.8	33.9	16.3

Table XVI. Analysis for bulk density, total porosity, and air capacity.

Soil	Depth Inches	Bulk Density	Porosity Per cent	Per cent of Total Soil Volume Drained At:	
				25 cm. H ₂ O Tension	50 cm. H ₂ O Tension
Ewen	0-3	1.40	42.4	3.6	6.0
	6-9	1.45	39.6	1.7	2.7
Propp	0-3	1.28	44.4	4.0	7.1
	6-9	1.39	43.1	2.8	4.2
Koyama	0-3	1.42	42.9	9.4	12.7
	6-9	1.39	41.9	3.3	5.5
Wagner	0-3	1.46	40.3	4.9	8.1
	6-9	1.51	38.0	3.2	4.5

Conductivity readings in the subsoils of the same four soils indicated the soluble salt content to be no higher than that existing in the surface. None of the subsoils showed higher pH values than would be expected from a saturated solution of calcium carbonate in equilibrium with the carbon dioxide of the atmosphere.

Bulk density determinations on the Ewen, Propp, Koyama, and Wagner soils indicated high values for both surface soils and subsoils. As a result, total pore space was found to be quite low with most of the samples having a total pore space of about forty per cent. The air capacity of the surface soils, as measured by the total soil volume drained at fifty centimeters of water tension, was found to be very low for the Ewen, Propp, and Wagner soils. The air capacity of the Koyama surface soil was slightly higher but was probably inadequate for the best growth of sugar beets according to the values suggested by Bayer (2).

Correlations between the various soil properties as determined by the analysis and available phosphorus as measured by the CO_2 extraction method are recorded in Table XVII. None of the individual soil factors showed a significant correlation with CO_2 soluble phosphorus. The correlations between CO_2 soluble phosphorus and the relative beet yield increases obtained with phosphorus fertilizer are listed in Table XVIII. The correlations obtained do not indicate a high degree of relationship to exist between CO_2 soluble phosphorus in soils and field response to phosphorus fertilization. Figure 3 illustrates the relationship between CO_2 soluble phosphorus and the beet yield increases obtained with applications of 80 pounds of P_2O_5 per acre.

Table XVII. Correlations between CO₂ soluble phosphorus and soil factors involved in phosphorus availability.

Factor correlated with CO ₂ soluble phosphorus	Correlation
1. Acid soluble calcium	-0.49
2. Acid soluble magnesium	-0.47
3. Calcium/magnesium ratio with acid soluble calcium and magnesium	-0.47
4. Extractable calcium	-0.63
5. Extractable magnesium	-0.26
6. Calcium/magnesium ratio with extractable calcium and magnesium	-0.18
7. Sum of acid soluble divalent cations	-0.49
8. Sum of extractable divalent cations	-0.66
9. Extractable sodium	-0.43
10. Extractable potassium	0.50
11. Sum of extractable monovalent cations	-0.13
12. Ratio of sum of extractable divalent cations to sum of extractable monovalent cations	-0.49
13. Free lime	-0.16
14. Organic matter	0.15
15. Two micron clay	-0.52
16. Exchange capacity	-0.54
17. Ratio: $\frac{\text{Sum of extractable divalent cations} \times \text{Exchange Capacity}}{\text{Sum of extractable monovalent cations}}$	-0.91**

** Indicates a significant correlation at the 1% level of significance.

Table XVIII. Correlations between CO₂ soluble phosphorus and relative beet yield increases obtained with phosphorus fertilizer.

Factor correlated with CO ₂ extractable phosphorus	Correlation
1. Relative increase in beet yield provided by 80 - 80 - 0 fertilizer over that provided by 80 - 0 - 0.	-0.24
2. Relative increase in beet yield provided by 80 - 160 - 0 fertilizer over that provided by 80 - 0 - 0.	-0.28

Table XIX. Correlations between soil organic matter and the nitrate content of the soils prior to incubation, the nitrate content after incubation, and nitrates produced during incubation.

Factor correlated with soil organic matter	Correlation
1. Nitrate content of the soil prior to incubation	0.76*
2. Nitrate content of the soil after incubation	0.77*
3. Nitrates produced during incubation	0.40

* Indicates a significant correlation at the 5% level of significance.

Table XX. Correlations between the initial nitrate content of the soil and the relative beet yield increases obtained with nitrogen fertilizer.

Factor correlated with the initial nitrate content of soils	Correlation
1. Relative increase in beet yield provided by 40 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.37
2. Relative increase in beet yield provided by 80 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.44
3. Relative increase in beet yield provided by 160 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.48

Table XXI. Correlations between the nitrate content of the soils after incubation and relative beet yield increases obtained with nitrogen fertilizer.

Factor correlated with the final nitrate content of soils	Correlation
1. Relative increase in beet yield provided by 40 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.34
2. Relative increase in beet yield provided by 80 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.55
3. Relative increase in beet yield provided by 160 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.42

Table XXII. Correlations between the nitrates produced in the soils during incubation and the relative beet yield increases obtained with nitrogen fertilizer.

Factor correlated with nitrates produced during incubation	Correlation
1. Relative increase in beet yield provided by 40 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.34
2. Relative increase in beet yield provided by 80 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.43
3. Relative increase in beet yield provided by 160 - 160 - 0 fertilizer over that provided by 0 - 160 - 0.	-0.42

Presented graphically in Figure 1 is the relationship found to exist between the ratio $\frac{\text{Sum of extractable divalent cations}}{\text{Sum of extractable monovalent cations}}$ (Exchange Capacity) and CO_2 soluble phosphorus. Figure 2 shows the same relationship expressed graphically using the logarithms of both factors. A correlation of -0.91 was found to exist between this ratio and the CO_2 soluble phosphorus in the soil. This correlation was found to be highly significant statistically.

Correlations between the various values of nitrate nitrogen and soil organic matter are given in Table XIX. The nitrate content of the soils before incubation and after incubation were found to be significantly correlated with soil organic matter. However, the correlation between nitrates produced during incubation and soil organic matter were not statistically significant.

The correlations between the various values of nitrate nitrogen and field response to applications of nitrogen fertilizer are listed in Tables XX-XXII. None of the nitrate nitrogen values were found to be significantly correlated with field response to nitrogen fertilizer applications.

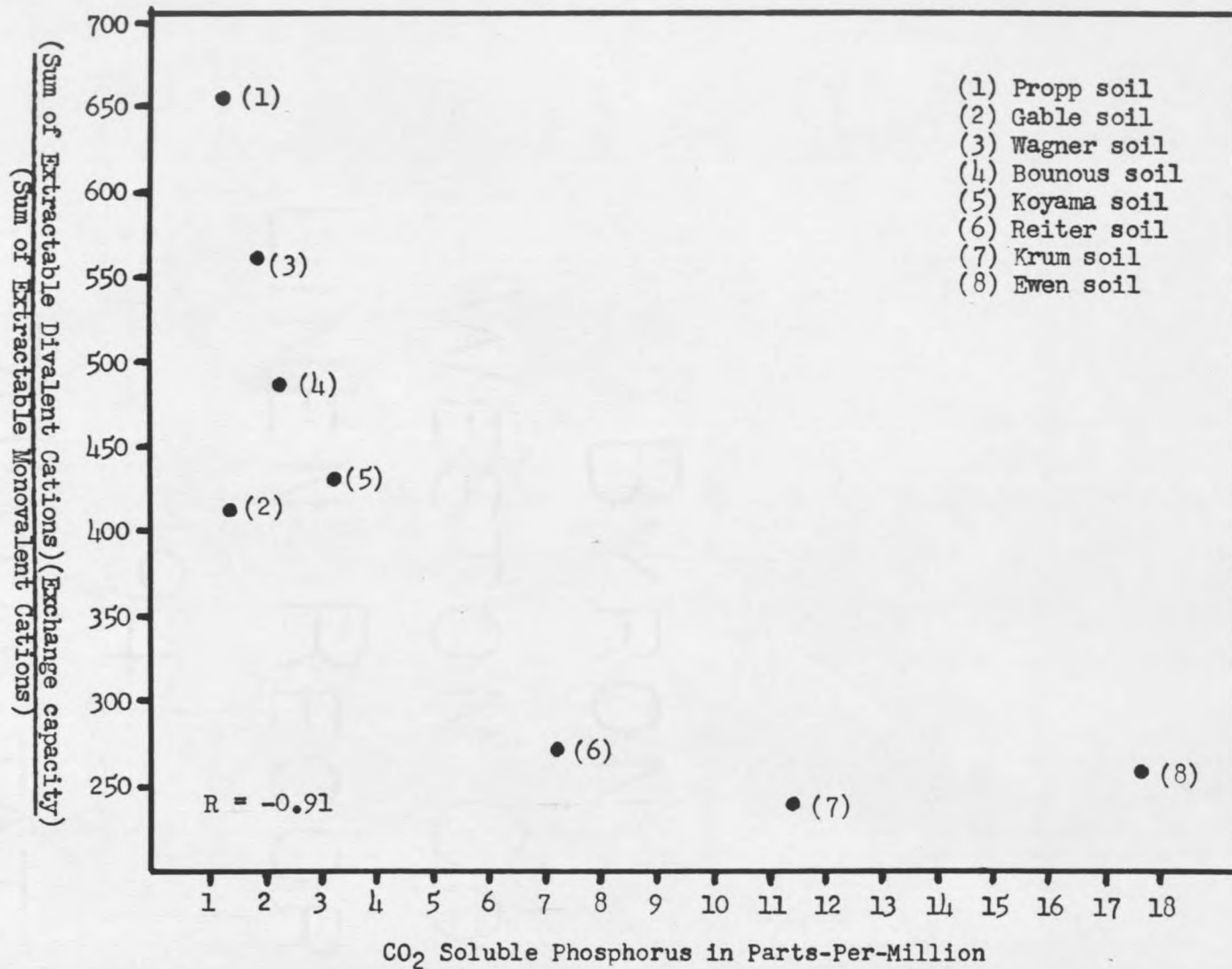


Fig. 1 Linear relationship between the ratio of negative to positive factors concerned in phosphorus solubility in the soil and CO_2 soluble phosphorus.

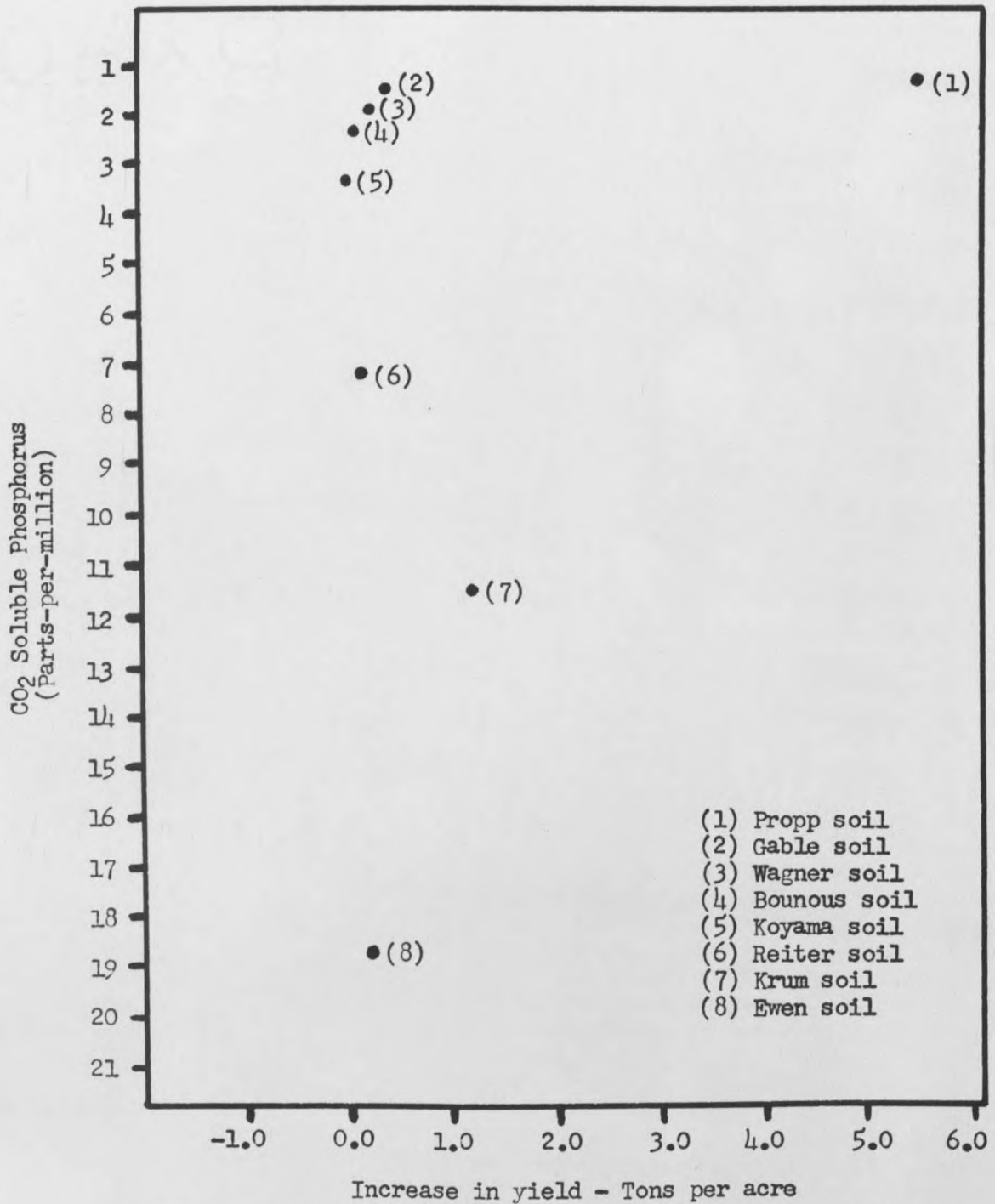


Fig. 3 Increase in yield of sugar beets from eighty pounds per acre of P₂O₅ as compared to the CO₂ soluble phosphorus present in the soil.

DISCUSSION

One of the most significant points to be noted in the results of this study is that no single chemical entity shows a high degree of relationship to CO_2 soluble phosphorus in the soil. This indicates that there is probably a group of interacting soil factors that influences the availability of soil phosphorus rather than any single factor. The single factor showing the highest correlation with CO_2 soluble phosphorus was extractable calcium with a correlation of -0.63 . This correlation approaches significance at the 5% level.

It is probable that most of the calcium removed as extractable calcium exists in ionic or readily soluble molecular combinations in the soil. As such, it could influence the availability of phosphorus in two ways: (1) by the common ion effect, and (2) by providing cations that are highly effective in precipitating ionic phosphorus. By its common ion effect, ionic calcium tends to reverse reactions that would release phosphorus from insoluble or slightly soluble calcium phosphate forms. By its existence in the soil solution in high concentration, it tends to precipitate phosphate ions that are released by other reactions in the soil.

Free lime showed almost no relationship to CO_2 soluble phosphorus in these soils. The Propp soil has a free lime content that should be favorable for phosphorus availability, but it has the lowest content of CO_2 soluble phosphorus of any of the eight soils. The Krum soil, on the other hand, has more than two per cent free lime and a high content of CO_2 soluble phosphorus.

The acid soluble calcium content of the soils shows some degree of

relationship to CO_2 soluble phosphorus with a correlation of -0.49 existing between the two sets of values. This correlation is not significant and is notably less than the correlation obtained between extractable calcium and CO_2 soluble phosphorus. It is probable that acid soluble calcium is related to available phosphorus only because there is a high degree of relationship between acid soluble calcium and extractable calcium in the soil.

Neither acid soluble nor extractable magnesium were indicated to favorably influence phosphorus availability in these soils. On the contrary, the negative correlation obtained between acid soluble and extractable magnesium and the CO_2 soluble phosphorus content of the soils indicates that magnesium may be detrimental to phosphorus availability. This observation would seem to nullify considerations that the calcium-magnesium ratio might be a factor in phosphorus availability in these soils.

It is difficult to determine the forms of magnesium extracted from the soil by the hydrochloric acid extraction. This extraction was designed to measure the magnesium existing as dolomitic limestone without appreciably affecting the clay minerals in the soil. However, the breakdown of montmorillonitic type minerals or of primary minerals containing magnesium apparently did occur in this extraction, since considerably larger quantities of magnesium were extracted than could be accounted for as dolomitic limestone, soluble salts, and exchangeable magnesium. In view of this observation, the validity of comparisons between acid soluble magnesium as measured in this analysis and CO_2 soluble phosphorus is open to question.

Extractable potassium was found to be positively correlated with CO_2

soluble phosphorus, but the correlation value of 0.50 was not significant. Extractable sodium showed a negative correlation value of 0.43 with CO_2 soluble phosphorus despite the well known solubility of sodium phosphates. However, it is probable that sodium had only a very small effect in some of the soils which were very low in extractable sodium.

Organic matter content showed little correlation with CO_2 soluble phosphorus. Apparently the carbon dioxide released in the breakdown of native soil organic matter is insufficient to appreciably affect phosphorus availability in these soils.

The -0.55 correlation for exchange capacity and CO_2 soluble phosphorus and the -0.52 correlation for two micron clay and CO_2 soluble phosphorus indicates that colloidal clay may be a negative factor in phosphorus availability. The adsorption of phosphorus by clay is generally discounted in alkaline soils since hydroxyl ions are present which are capable of releasing adsorbed phosphates from clays by anion exchange. However, the hydroxyl ion concentration at pH 7.7 is only $5 \times 10^{-7} \text{ N}$. If anion exchange is an equilibrium reaction, the hydroxyl ion concentration indicated above would seem to be inadequate to prevent considerable adsorption of phosphate by clays.

A relationship between the CO_2 soluble phosphorus, colloidal clay, and the composition of the cationic solution was observed in this study. It was found that the ratio:

$$\frac{(\text{Sum of extractable divalent cations})(\text{Exchange Capacity})}{(\text{Sum of extractable monovalent cations})}$$

gave a -0.91 correlation with CO_2 soluble phosphorus in these soils. With

the small number of soils studied, it is difficult to establish whether this relationship is coincidental or whether it represents a true relationship between the factors involved. With odds of at least 99 to 1 that it is not due to chance, this relationship justifies further investigation.

Due to the limited amount of data obtained, interpretation of this relationship would be beyond the scope of this study. However, it can be pointed out that the factors involved are logically related to phosphorus availability. The phosphates of the divalent cations all show low solubility in water, while the phosphates of the monovalent cations are quite soluble in water. In calcareous soils with appreciable exchangeable sodium, phosphate solubility is usually high because calcium solubility is depressed and sodium phosphates are formed. A similar relationship probably exists between potassium, calcium, and phosphorus since potassium is similar to sodium in its chemical properties and reactions. In this study, the correlation between the sum of the divalent cations and CO_2 soluble phosphorus was found to be -0.66 which approaches significance at the 5% level. The work of Scarseth (14) and Pratt and Thorne (10) indicate that the amount of adsorption of phosphorus by clay colloids may be proportional to the cation composition of the soil solution. Thus, there is a logical basis for expressing the extractable cations as a ratio in this relationship.

The influence that the cation exchange capacity might exercise in this relationship is not immediately apparent excepting that it is highly correlated with clay content and is probably highly correlated with the anion exchange capacity of the clay colloids.

To establish the validity of this relationship, it would be desirable

to have these ratios and CO_2 soluble phosphorus data for a hundred or more soils. If a high correlation were then obtained, the ratio would probably be valid.

No significant correlations were obtained between nitrifiable nitrogen and other soil factors. This is not too surprising since nitrification in soils is dependent upon biological forces and other outside influences such as temperature and moisture. The amount of native soil organic matter is often found to influence nitrogen availability in the soil, but the correlation between native soil organic matter and nitrifiable nitrogen in these soils was found to be only 0.40. While some degree of relationship is indicated, the correlation obtained was not significant. Lime content showed little or no relationship to nitrifiable nitrogen.

A correlation of 0.77 was obtained between the original nitrate content of the soil and soil organic matter. This correlation approaches significance at the 1% level, and it indicates a strong relationship between the nitrate level in the soil and soil organic matter levels. However, the original soil samples were not exposed to air drying for equal periods of time, and special precautions were not taken to minimize bacterial activity in the soils. Therefore, the nitrate content of these soils may be a function of the time and conditions under which they were exposed to air drying. Under these circumstances, too much emphasis should not be placed on the high correlation value obtained.

A similarly high correlation of 0.76 was obtained between the level of nitrates in the soil after incubation and soil organic matter. However, this correlation probably results largely from the original nitrate levels

in the soil before incubation since the amounts of nitrates produced during incubation were similar for most of the soils.

The original level of nitrates in the soil also seems to be related to the cropping history of the soil. The Gable soil was only one year removed from alfalfa and showed the highest initial level of nitrates. The Propp soil had been seeded to beans, a nitrogen fixing legume, in 1949 and 1947. Prior to 1946 this field had been seeded to alfalfa. This soil showed the next highest content of nitrates prior to incubation. However, interpretation of this relationship is subject to the same limitation as was encountered in the organic matter-nitrate level correlation since the initial nitrate level of the soils may be related to the method of handling the soil samples.

A high total content of nitrates after incubation was noted in the Reiter soil, but there is little in the previous history of the field or the chemical data obtained to account for the nitrate producing ability of this soil. However, the cropping history is available for only four years. Oddly enough, this soil gave the second highest response to nitrogen fertilizer of the eight soils in the study.

The Ewen soil produced the least nitrate upon incubation and it gave the best field response to nitrogen fertilizer. Manure had been applied to this field in 1946 and 1949, and nitrogen fertilizer was applied in 1946, 1948, and 1949. However, rates of application of the manure or fertilizer are not known.

Neither nitrifiable nitrogen nor nitrate content before incubation are indicated to be sufficiently correlated with field response to nitrogen to

be of use in predicting the need for nitrogen fertilizer. Both nitrifiable nitrogen and nitrate content before incubation show correlations of about -0.40 with field response to nitrogen fertilizer. This indicates that some degree of relationship exists between these values and the need for nitrogen fertilization, but the degree of relationship is not high.

The correlations obtained between soil organic matter and response to nitrogen fertilizer in the field were low for the comparisons made at the 80 and 160 pound rates of application. At the 40 pound rate of nitrogen application, a somewhat higher correlation of -0.44 was obtained. However, aside from the generally low degree of relationship between soil organic matter and field response to nitrogen fertilization, interpretation of soil organic matter values within the narrow range observed in these soils would be difficult indeed. Thus, organic matter content would seem to be of very limited value in predicting the need of these soils for nitrogen fertilization.

From the limited data obtained, it appears that past cropping history may be as reliable as soil analysis methods in evaluating the need of a field for nitrogen fertilization. Especially do the number of years a field has been removed from alfalfa or other leguminous crops seem to be an indication of the nitrate producing ability of the soil.

The low correlation values obtained between relative beet yield increases from phosphorus fertilization and CO_2 soluble phosphorus would seem to indicate that the CO_2 extraction method does not accurately predict the available phosphorus status of the soil. However, only the Propp soil showed a definite response to phosphorus fertilization, and it is possible

that the correlation values obtained were determined largely by small variations in yield occurring on the seven soils in which little or no response was noted. Since the value of the CO_2 extraction for available phosphorus in calcareous soils has been verified by more extensive studies (3), there seems to be little justification for questioning its validity on the basis of the limited data obtained in this study.

On the basis of the data obtained in this study, little response to phosphorus fertilization can be expected when the CO_2 soluble phosphorus in the soil exceeds 2.5 parts-per-million. This value partially substantiates the standard currently in use by the Montana Experiment Station in which 3.26 parts-per-million of CO_2 soluble phosphorus is considered to be the dividing value between the medium and low range of available phosphorus in the soil. On the basis of this study, it would appear that the medium range should be between 2.0 and 3.5 parts-per-million of CO_2 soluble phosphorus.

Of interest is the ability of some of the soils to produce relatively high tonnages of beets without fertilization despite low values for available phosphorus as determined by soil analysis. For instance, the unfertilized plots on the Bounous soil produced an average yield of 17.5 tons of beets per acre, although the soil test indicated that the soil contained only 2.20 parts-per-million of CO_2 soluble phosphorus.

For soils showing low values for CO_2 soluble phosphorus, responses to phosphorus fertilization were quite erratic. The Propp soil, having 1.25 parts-per-million of CO_2 soluble phosphorus, provided a yield increase of 5.1 tons per acre to 160 pounds of P_2O_5 per acre applied alone. The Gable soil, with 1.40 parts-per-million of CO_2 soluble phosphorus, showed only

1.7 tons per acre increase in yield to 160 pounds of P_2O_5 per acre. It does not seem logical that the difference of 0.15 parts-per-million of CO_2 soluble phosphorus between the two soils could account for the 3.4 tons per acre greater yield increase obtained on the Fropp soil. This emphasizes a serious drawback encountered in soil analysis; namely, that our present methods of soil testing do not measure the ability of the soil to replace nutrients absorbed by plants. This, in the final analysis, is more important than the initial concentrations existing in the soil.

No attempts were made to correlate relative beet yield increases from potassium fertilization and the extractable potassium content of the soil since no definite beet yield increases were obtained with potassium applications in the field tests. Moreover, all of the soils were indicated to contain large reserves of available potassium as measured by the ammonium acetate extraction.

As previously noted, the highest average yields of beets obtained in most of the tests were not high considering the liberal applications of fertilizer made in these tests. It, therefore, seems likely that some factor other than the availability of fertilizer elements in the soil is limiting the yields of beets on these fields. From the data obtained, it appears that a lack of soil aeration may be a limiting factor in the yield of sugar beets on these soils. Sugar beets are noted to be a crop that is sensitive to poor soil aeration, and Bayer (2) suggests that an air capacity of 15-20% is desirable for the best growth of sugar beets. It is interesting to note the air capacities of the 0-3 inch and 6-9 inch layers of the Ewen, Fropp, Koyama, and Wagner soils. At 50 centimeters of water tension, the

air capacities in the 0-3 inch layer are only 6.0, 7.1, 12.7, and 8.1 per cent respectively. In the 6-9 inch layer where the beets could be expected to absorb much of their water and nutrients, the air capacities of these same four soils are only 2.7, 4.2, 5.5, and 4.5 per cent respectively. Thus, it appears likely that increases in beet yields might be obtained on these fields with improved soil aeration. However, such improvement in aeration is difficult of attainment since the only practical means of increasing the air capacity of a soil involves the improvement of soil structure. This is a slow process which involves careful and timely tillage, additions of organic matter, and the inclusion of grass crops in a rotation whenever feasible.

A practice that may be of benefit immediately, is the planting of the sugar beets in ridges. Of interest in this regard is the average yields for ridged and unridged fields obtained in these tests with 80-160-0 fertilizer treatment which gave the highest overall average yield for all tests. The average for this treatment on the three ridged soils was 18.4 tons per acre, and the average of the five unridged soils for the same treatment was 16.0 tons per acre. Such a comparison involving different soils is probably not valid, but the comparison is probably unfavorable for the ridged soils since they are the three heaviest textured soils of the group and are the most likely to be poorly aerated from a texture standpoint.

SUMMARY

Eight field fertilizer tests were conducted on irrigated sugar beets in Yellowstone and Big Horn counties on slightly alkaline calcareous and non-calcareous soils. Various combinations of nitrogen, phosphorus, and potassium fertilizers were applied to the soils studied in these tests, and the effects of the fertilizer on beet yields, sugar content, and total sugar production were measured on each field. Chemical, physical, and mechanical analyses were performed on samples of soil taken from each field, and the chemical characteristics of the soils were correlated with the response to fertilizer obtained in the field in order to establish a basis for a reliable soil analysis program. Correlation methods were used to measure the relationship of various soil factors to the availability of nitrogen and phosphorus in the soil as measured by chemical analysis. The results of the field tests on these soils indicate that:

1. Nitrogen was the most deficient fertilizer element in six of the eight soils studied. With these soils, phosphorus showed little response when applied alone but gave small increases in yield when used in combination with nitrogen.
2. Phosphorus was the most deficient fertilizer element in two of the eight fields. Nitrogen produced little additional response on these fields.
3. Potassium was not deficient in any of the fields excepting for one soil in Yellowstone County which gave a doubtful response to potassium fertilization.
4. The 40 pound per acre rate of nitrogen application, in general,

gave equal responses to that obtained with the 80 and 160 pound per acre rates, and the 80 pound per acre rate of P_2O_5 gave equal yield increases to that obtained with 160 pounds of P_2O_5 per acre.

5. Nitrogen produced significant decreases in the sugar content of the beets with decreases of 0.18, 0.55, and 1.27 per cent sugar being noted with the 40, 80, and 160 pound rates of nitrogen application respectively.
6. Phosphorus and potassium had little effect on the sugar content of the beets.
7. Nitrogen and phosphorus fertilizer combinations, in general, gave the greatest yields of total sugar.

The results of the chemical analyses of these soils indicate that:

1. Little yield response to phosphorus fertilization on sugar beets occurred when the soil contained more than 2.5 parts-per-million of CO_2 soluble phosphorus.
2. The amount of nitrates produced in the soil during incubation under constant conditions of temperature and moisture were not sufficiently correlated with field response to nitrogen fertilizer to provide a reliable basis for predicting the need of a soil for nitrogen fertilization.
3. The native soil organic matter content, within the narrow range encountered in these soils, was of little value in predicting the need of a soil for nitrogen fertilization.
4. The past cropping history of a field, especially in regard to the number of years the field is removed from alfalfa, may be as useful

as most of the current chemical methods in predicting the need of soils for nitrogen fertilization.

5. Concentrations of free lime bore little relationship to the CO₂ soluble phosphorus content of the soil.
6. The two most effective soil factors in reducing the amount of CO₂ soluble phosphorus in the soil were ammonium acetate extractable calcium and colloidal clay.
7. CO₂ soluble phosphorus decreased in the soil as the proportion of ammonium acetate extractable divalent cations to the ammonium acetate extractable monovalent cations increased.
8. The ratio:
$$\frac{\text{(Sum of extractable divalent cations)(Exchange Capacity)}}{\text{(Sum of extractable monovalent cations)}}$$
 was highly correlated with the CO₂ soluble phosphorus content of the soil.
9. Acid soluble calcium was not effective in depressing the CO₂ soluble phosphorus content of the soil excepting as it may have contained or became a source of ammonium acetate calcium in the soil.
10. Neither acid soluble nor ammonium acetate extractable magnesium effectively increased phosphorus solubility in the soil as measured by the CO₂ extraction method.
11. Native soil organic matter bore little or no relationship to the CO₂ soluble phosphorus content of the soil.
12. Calcium/magnesium ratio for either acid soluble or ammonium acetate extractable calcium and magnesium was not a major factor in determining the CO₂ soluble phosphorus content of the soil.
13. The soils contained from 630 to 1400 pounds of extractable potassium

per acre furrow slice. The soils were not deficient in available potassium according to the standards employed in eastern United States.

The results of the physical analyses of these soils indicate that:

1. The total porosity of the Ewen, Propp, Koyama, and Wagner soils was lower than the total porosity of most soils of a similar texture.
2. The air capacities of the Ewen, Propp, Koyama, and Wagner soils were much lower than has been found by other workers to be desirable for the best growth of sugar beets.

It is apparent that some of the results obtained in this study are not in agreement with the results obtained by other workers investigating similar soils. Inasmuch as this study was limited in scope, it would be desirable to conduct similar studies on a more extensive scale to clarify these discrepancies and to arrive at a clearer understanding of fundamental soil fertility relationships in alkaline calcareous and non-calcareous soils.

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