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

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.

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

at

Montana State College

Approved:

A. H. Post
Head, Major Department

J. C. Hide
Chairman, Examining Committee

J. M. Nelson
Dean, Graduate Division

Bozeman, Montana
June, 1951

ACKNOWLEDGMENT

The writer wishes to acknowledge the assistance given him by the staff members of the Agronomy and Soils Department, especially Dr. J. C. Hide, Mr. J. A. Asleson, and Dr. W. E. Larson who suggested the problem and gave valuable advice and assistance during the course of this study. Acknowledgment is also due to Dr. E. R. Hehn for his suggestions on the analysis and statistical interpretation of the data obtained.

The writer wishes to express his appreciation to Dr. W. E. Larson of the Bureau of Plant Industry, Soils, and Agricultural Engineering of the United States Department of Agriculture who generously contributed the data pertaining to the field fertilizer trials that made this study possible, as well as valuable laboratory analysis data.

TABLE OF CONTENTS

LIST OF TABLES

(continued on page 5)

LIST OF TABLES (continued)

LIST OF FIGURES

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. Nitrogen 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. 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.

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 CO_2 soluble phosphorus content of the soil. A ratio expressing all of these factors was found to have a -0.91 correlation with the CO_2 soluble phosphorus content in the soil.

THE RELATIONSHIP BETWEEN THE CHEMICAL AND PHYSICAL PROPERTIES OF EIGHT MONTANA SOILS AND THEIR RESPONSE TO FERTILIZATION

by

GLENN P. HARTMAN

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 carbonato-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 treble 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_2O_5	K_2O
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, P_2O_5 = Phosphoric acid, K_2O = 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 CO_2 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