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THE RELATIONSHIP BETWEEN SOIL TEST AND SMALL GRAIN RESPONSE TO P FERTILIZATION IN SOUTH DAKOTA FIELD EXPERIMENTS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the department.

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Thesis Advisor Date

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Head, Plant Science Dept. Date

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INTRODUCTION

Phosphorus is one of the two most limiting nutrients to crop production in South Dakota. Because of this fact, many recommendations for P fertilizer are made each day by the South Dakota State University Soil Testing Lab.

Nearly 65,000 tons of available P are marketed each year in South Dakota as commercial fertilizer. This amounts to over 18 million dollars of expense for South Dakota farmers. Therefore, it becomes essential that recommendations for phosphorus fertilizer be as accurate as our knowledge of the soil-plant system allows.

Those recommendations are currently based on the results of the Modified Bray 1, 1:7 soil test, a test used by many states throughout the Midwest. Based on data collected from 74 small grain field experiments over a 13-year period, this test explains less than 30% of the variation in yield response to P fertilization.

The purpose of this study was twofold: (1) to compare several alternative soil tests on the basis of field response data; and (2) to evaluate the influence of several factors on the relationship between soil test and yield response to P fertilization.

REVIEW OF LITERATURE

The nature of available soil phosphorus will be discussed in the first portion of this literature review. This will be followed by a review of the research conducted with two soil tests for available P and their relation to soil P fractions. Factors influencing the relationship between soil P tests and response to P application will be the subject of the final portion of this review.

I. Available Soil Phosphorus

Soil phosphorus is a dynamic mixture of numerous compounds and phases influenced by several soil factors. Williams (63) considered four components of available soil P that must be determined to define the P status of a soil. The first of the four factors was the quantity factor which Williams defined as the total amount of available P in the soil. This represents the labile pool of isotopically exchangeable P which is often expressed as the "L value" of a soil.

The intensity factor represents the ease or difficulty of withdrawal of P and, in simplest form, is equivalent to the P concentration in soil solution. It is normally determined as inorganic P extractable by .01M $CaCl_2$ or by water. Hagan and Hopkins (21) showed that both $H_2PO_4^-$ and $HPO_4^=$ are absorbed by barley roots from the soil solution and are, therefore, likely the main form of P included in this factor.

The third factor was the capacity. This represents the relationship between quantity and intensity and is often referred to as the phosphate-buffering capacity. It defines the ability of the soil to maintain the intensity during the growth of crops. The fourth factor was a rate factor which indicates the ability of the soil to transport P to the root.

Dalal and Hallsworth (11) evaluated these four factors in a study of eight Australian soils. They used several tests for each factor and found that soil tests which estimate the quantity factor were most related to grain yield in field experiments and explained up to 93% of the variation in grain yield.

Several investigators have found that soil tests which measure the quantity factor are also correlated with the aluminum phosphate fraction as determined in the procedure of Chang and Jackson (9,42, 52,61,66). Murrmann and Peech (31) reported that this fraction was most significant in controlling the soil solution P concentration and must also include adsorbed or labile P. Coleman (10) showed that good growth of cotton and oats resulted from montmorillonitic and Kaolinitic clays which had been previously purified and allowed to adsorb P.

Although surface P measurements alone do not tend to be proportional to available or equilibrium P concentration, Rennie and McKercher (45) showed that the percent saturation of the adsorption maximum may serve as a measure of the capacity of the soil to supply P to the soil solution. They reported that organic matter was equally important as clay in determining the adsorption capacity of soil and that soils high in organic matter may hold P with greater bonding energy than low organic matter soils. Vijayachandran and Harter (57) concurred with this conclusion and went on to indicate that hydroxy aluminum compounds on clay surfaces as well as anion adsorption sites on organic matter correlated with the Langmuir adsorption maximum.

Seyers et al. (48) studied three Brazillian soils and found that they sorbed more P as the pH decreased from 5.2 to 3.7. Olsen and Watanabe (37) showed that acid soils retained more P per unit of surface area and held the P with a greater bonding energy than alkaline soils.

The P adsorption maximum and the equilibrium solution concentration of P, according to Woodruff and Kamprath (64), should be helpful when studying soil tests for available P. They proposed that with these values, soils could be grouped together which require the same level of available soil P for maximum growth.

The role of organic phosphorus in the P nutrition of plants has been a controversial issue. Thompson and Black (54) incubated Iowa soils for 30 days at 35° C and found 19.1 ppm P mineralized in virgin soils and 6.3 ppm in cultivated soils. Singh and Jones (49) similarly reported mineralization for the first 30 days of incubation at room temperature. After 75 or 150 days, however, they found that more P was sorbed by soil if the P level in added organic residue dropped below 0.3%. This indicated that immobilization may have been occurring. Net mineralization did not occur in these soils till after 150 days of incubation with the low P residue. Halstead et al. (22) reported that for soils of eastern Canada, part of the beneficial effect of lime on P availability is due to mineralization of organic P amounting to 5 to 8 ppm.

Organic P, in certain soils, has significantly influenced P mobility. Hannapel et al. (23) added sucrose to calcareous Arizona soil and increased the amount of P movement 38-fold with more than 95% of the P moving being organic.

The amount of organic P in some soils has been related to response of crops to P application. In 31 field experiments with wheat in East Africa, 10 soil P tests were evaluated by Friend and Birch (17). Total organic P was most highly correlated with P response in these soils. Organic P, however, represented 86% of the total soil P which is considerably more than the 50% reported in South Dakota soils by Westin and Buntley (62). In a greenhouse study of 17 acid Iowa soils, Eid et al. (13) found that at 20° C, availability of soil P to corn plants was most highly correlated with inorganic P (Bray 1 extractable) but at 35° C organic P soluble in hot 1% K_2CO_3 and hydrolyzed by hypobromite related most to available P. In a study of 8 small grain field experiments in Australia, Dalal and Hallsworth (11) reported a correlation coefficient of .92, which was significant at the .01 level, between grain yield and organic P.

Several studies have been conducted evaluating the ability of plant roots to utilize organic P. Estermann and McLaren (14) found that barley roots produced the enzyme phosphatase in the root cap and on the epidermis. They reported that this enzyme may allow barley to utilize organic P and urea through hydrolysis of these compounds by the root and rhizoplane organisms. They also reported the temperature optimum of this enzyme was 38° C and the optimum pH was 5.3. In another study by Greaves and Webley (19), a large number of organisms in the root region of perennial ryegrass, timothy, and cocksfoot were found that could attack organic phosphates such as phenolphthalein diphosphate, glycerophosphate, and sodium phytate. They went on to state that no definite conclusion could be made regarding the relationship between microbial breakdown of soil organic P and P nutrition of the plant. For the most part, the nature of the contribution of organic phosphorus in plant nutrition remains a mystery.

II. Soil Tests for Available P

Numerous quick soil tests for available P have been proposed and evaluated under various conditions. Two of the most successful tests for midwestern soils have been the Bray 1 (5) which uses an extracting solution of dilute NH_4F and HCl, and the Olsen method (36) which extracts with $NaHCO_3$. These tests have been evaluated under both greenhouse and field conditions in many states and several countries. A summary of some of these studies follows.

Greenhouse or Lab Studies

The phosphate fraction(s) extracted by these tests have been evaluated at several locations with various results. In Michigan (52), Bray P correlated only with the Al-P fraction. In Minnesota (9) and North Dakota (66), Bray P correlated with both Al-P and Fe-P fractions while in South Dakota (61) and California (42), Bray P correlated with NH_4Cl-P and Al-P. In Michigan (52) and in Minnesota (9), Olsen P correlated with only Al-P. In North Dakota (66), Olsen P correlated with Al-P and Fe-P, but in South Dakota (61) with Al-P and Ca-P, and in California (42) with Al-P and NH_4Cl-P. The diversity of results is perhaps related to the diversity of soils studied.

The correlation between these P fractions, by the Chang and Jackson method (8), and P uptake or yield response has also been studied. In Indiana (1), P uptake by millet correlated with NH_4Cl-P, Al-P, and Fe-P. In North Dakota (66), sudangrass dry matter response to P correlated with Al-P, Fe-P, and Organic P. In Virginia (28), P uptake by oats correlated with Al-P and Ca-P, but in South Dakota (15), P uptake by barley correlated only with Al-P. Again, a diversity of results is obtained.

Comparisons of the Bray 1 and Olsen tests have been made evaluating the effectiveness of each test in correlating with P uptake or yield. In some instances, there appears to be no difference in effectiveness between the two tests (66,1,60). In other studies, the Bray 1 has been shown to be more highly correlated (33), while in some instances the Olsen procedure has been more related to P uptake (52).

Field Studies

Much less work has been reported under field conditions and the extension of the previously discussed greenhouse studies to field conditions may not result in correct conclusions.

A quite extensive study, including data from 75 small grain field experiments in Nebraska, was conducted by Olson et al. (34). Correlation coefficients between percent yield increase from P fertilization and soil test can be found in Table 1.

Table 1. Correlation coefficients between percent yield increase from P fertilizer and soil test for several Nebraska experiments.

	Bray 1	Olsen
40 wheat exp.	-.632**	-.577**
22 oats exp.	-.475*	-.513*
13 oats and wheat on calcareous soils	-.632*	-.575*

*Significant at .05 level

**Significant at .01 level

From this study, the authors divided the soil tests into response ranges. "Assured responses" occurred if Bray 1 P was $<$ 15 ppm or if Olsen P was $<$ 8 ppm. A "likely response" occurred if Bray P was 15-24 ppm and Olsen P 8-12 ppm. A "possible response" occurred if Bray P was 24-30 ppm or Olsen P 12-16 ppm. An "unlikely response" occurred when Bray P exceeded 30 ppm or Olsen P 16 ppm.

Russel (46) stated that correlation experiments, if done with a crop in the field, rarely result in correlation coefficients exceeding 0.7. He also made the following statement:

> It is now clear that there cannot be a universal simple and reliable method of soil analysis that will allow an accurate forecast of the amount of phosphate a crop can take up from a soil, for this depends, as already noted, not only on the P concentration in the soil solution and its rate of diffusion to the root surface, but also on the extensiveness of the root system and the amount of root hairs it carries, and this depends on soil and climatic factors unrelated to its phosphate status.

It is because of the points Russel summarizes in the previous quote that Part III is included in this literature review.

III. Factors Influencing P Response, P Availability Tests, and Their Interactions.

Influence of pH

Soil pH reflects not only the amount of the various P fractions occurring in a soil, but has been shown to influence organic P mineralization rates as well as the P sorption characteristics of a soil (48,37). Thompson et al. (55) reported that for 50 unlimed Iowa soils in both field and lab tests, organic P mineralization increased markedly with pH but organic carbon and nitrogen did not. They also reported that the ratio of total organic nitrogen and carbon to total organic P increased with soil pH.

In a greenhouse study of 137 Indiana soils, Al-Abbas and Barber (2) reported correlation coefficients between P uptake and Bray 1 P of .64, .53, and .55 at pH ranges of < 6, 6-7, and >7, respectively. They also reported correlation coefficients for Olsen P as .66, .53, and .55 at the same respective pH ranges. The indication, then, was that the slightly acid soils correlated somewhat poorer than the acid soils.

Another greenhouse study of 30 South Dakota soils conducted by Salami (47), showed no difference between acid and alkaline soils in their correlation between soil test P and percentage yield. The same study, however, showed a highly significant correlation between soil P test and P uptake for acid soils but no correlation between soil P test and P uptake for alkaline soils.

Influence of a Wider Soil : Solution Ratio of the Bray Test

Closely associated with pH is the $CaCO_3$ content of soils, at least for calcareous soils. Calcareous soils were defined simply by Olsen (35) as any soil containing $CaCO_3$. This will be the meaning associated with this term for the remainder of this paper.

In a study of calcareous Kansas soils ranging from 0.4 to 7.5% $CaCO_3$, Smith et al. (50) showed that $CaCO_3$ neutralized the acid of narrow soil to solution ratios of the Bray reagent before available P could be extracted. He pointed out that a soil containing only 0.88% $CaCO_3$ could neutralize all the acid in the 1:7 test, whereas, the 1:50 ratio had sufficient acid to react with a soil containing 6.25% $CaCO_3$. The rank correlation between percent maximum yield values and Bray extractable P was 0.63, .883, and .881 for soil to solution ratios of 1:7, 1:50, and 1:100, respectively.

Blanchar and Caldwell (4), in a study of calcareous Minnesota soils, reported a nonsignificant correlation coefficient of .23 between P uptake by oats in a greenhouse and Bray 1, 1:10 P. When the soil to solution ratio was increased to 1:50, the correlation coefficient increased to .89, which was highly significant. They also found a significant inverse relationship between P extracted by Bray 1, 1:10 or 1:50 and $CaCO_3$ when dolomite was subtracted from the $CaCO_3$ equivalence.

Influence of Genetic Origin

In a study of 270 Syrian soils, Matar and Samman (29) reported a nonsignificant correlation coefficient of a -.03 between Olsen P and relative yield increase from P in a greenhouse experiment. If the soils were divided into four groups based on genetic origin, however, correlation coefficients became significant.

In another greenhouse study of 30 South Dakota soils, Salami (47) showed a significant influence of parent material on the relationship between plant uptake of P and soil test. In this study, plant uptake of P was highly correlated with Bray 1:10 P, Bray 1:50 P, and Olsen P for the till soils but not significantly correlated for residual soils or soils developed from loess.

A more specific soil genetic characteristic, soil texture, has been found to influence soil tests in several instances. Olsen and Watanabe (38) reported that at the same P concentration in solution, the average rate of uptake (24 hours) was five times greater in the Pierre clay soil series than in the Tripp fine sandy loam series. On the other hand, Pratt and Garber (42), in a study of 29 California soils, showed that as clay content increased in soils, Bray extractable P decreased.

The Influence of Moisture and Temperature on P Yield Response

A significant influence of climate on yield response to P application has been noted in many studies. In a greenhouse study of 20 Oklahoma soils, Gingrich (18) showed that dry matter yield of winter wheat 24 days after planting was not influenced by application of P when the soil was maintained at 50° F regardless of P level present in the soil. His explanation for this phenomenon was that the rate of absorption and translocation was so low even the low P soil supplied sufficient available P. At 65° F, 8.8 ppm of P doubled the yield.

A study with North Dakota sandy loam soils by Power et al. (41), which was conducted in growth chambers using barley, provided evidence that growth responses on low P soils were very sensitive to soil temperature. They showed maximum response at 59° F with rapid decline if temperatures changed above or below this optimum. On medium P soils, response was much less dependent on soil temperatures. They also pointed out that this interaction causes correlation between available soil P and response to P fertilization to be very poor when a range of soil P levels and soil temperatures are included and may account for a significant amount of variability in field experiments in the Great Plains.

A study involving 53 winter wheat field experiments in Oklahoma over four years was conducted by Eck and Stewart (12). The resulting correlation coefficient between Olsen P and yield response from 20 pounds of P_2O_5 per acre was -.37 which was highly significant but explained less than 14% of the variation in response. They concluded that soil test alone could not be used as a reliable indicator of response to P. In the same study, degree days above 90° F for the final 20 days preceding harvest was most related to response from P fertilization (.629). The authors' explanation for this was added P hastens maturity so the wheat suffers less from the desiccating effect of high temperatures than unphosphated wheat.

Case et al. (7), in a greenhouse study with oats, reported maximum height response to applied P at 15° C, less at 20° C and lesser at 25° C. They suggested that soil temperature effects on oat plants were at least twofold: (a) a direct effect on the physiology of the plants due mainly to increased translocation of P from roots to tops, (b) an indirect effect due to an increase in the rate of mineralization of organic P with increasing soil temperature.

In a review article, Sutton (53) summarizes that there is good evidence that low soil temperature can reduce the availability of inorganic P to plants and may, in some cases, reduce the quantity of available P.

An influence of moisture has also been noted by several investigators. Olsen et al. (39) reported that for a group of calcareous Colorado soils, a linear positive relationship existed between P uptake and moisture content for a given soil. In a four-year field study of 13 fallowed sites in Montana conducted by Power et al. (40), yield increase from P fertilizer had a correlation coefficient of .73 with soil moisture at seeding and .90 with available soil moisture at seeding plus precipitation between tillering and heading.

Mack and Barber (27) showed an interaction between moisture and temperature in a greenhouse study of Indiana soils. An increase in moisture content was associated with an increase in the dry weight and P uptake at the higher soil temperature (27° C), but not at the lower soil temperature (16° C).

Raguse and Evans (43) reported that even small physical modifications in soil profile, aspect of soil surface, or seasonal climatic changes influence P uptake and mobilization of P by subterranean clover. Franklin (16) reported that raising the ionic strength of the absorbing solution of oats, wheat, and barley stimulated P uptake. This indicates that even slight changes in microrelief of a soil would likely influence the P status of the plant growing in it.

A summary of this review would indicate that the accuracy of soil tests in predicting response to P fertilization varies. Much of the research conducted has been under greenhouse conditions and may not fit the varying conditions of the field. In the field, factors such as pH, $CaCO_3$ content, soil genetic origin, moisture, and temperature may influence the relationship between soil test and response to P fertilization.

To study these relationships, field experiments were established in South Dakota using rates of phosphate fertilizer as the variable. Yield response data and the corresponding soil samples from these experiments were used to evaluate soil P tests and the influence various factors have on the correlation between soil tests and yield response to added P. The ultimate objective was greater predictability of the P-supplying power of South Dakota soils. This, in turn, should provide South Dakota farmers with more accurate P fertilizer recommendations.

METHODS AND MATERIALS

Field Methods

The yield data used in this study was the result of 74 small grain experiments conducted in South Dakota between 1963 and 1975 as a part of the South Dakota State University soil fertility program. The locations of the experiments are shown in Figure 1. The year of the experiment, crop species, location, and classification of the soil at the experimental site is given in Table 2. In all cases, the phosphorus fertilizer was applied with the seed.

Laboratory Methods

The air dried soils for this study were ground to pass through a 2 mm sieve. They were stored in plastic bags at room temperature from the date of the experiment to the time at which the soil phosphorus tests were conducted.

Exchangeable K, % organic matter, texture, and pH were determined by the South Dakota State University Soil Testing Laboratory (6). Organic matter was determined by a modification of the Walkley-Black method. The soil pH was measured in a 1:1 soil to water paste and the texture class was determined by the ribbon method.

Seven phosphorus soil test methods were used in this study. The ratios, following the names of the first 4 tests refer to the soil to solution ratio used. The procedures were as follows:

Modified Bray-1, 1:7 (6) In this method, a 1.5-gram soil sample was shaken with 10 ml of 0.03N NH_4F, 0.025N HCl in a 50 ml erlenmeyer flask for 2 minutes at 190 OPM. The extracts were filtered and phosphorus determined by the Fiske-Subbarrow method (26). This is the method currently used by the South Dakota State University Soil Testing Laboratory.

Modified Bray-1, 1:10 This method was identical to the above 1:7 test, except that 1.0 gram of soil was used.

Modified Bray-1, 1:20 One gram of soil was shaken with 20 ml of 0.03N NH_4F, 0.025N HCl in a 125 ml erlenmeyer flask for 2 minutes at 190 OPM. The extracts were filtered and phosphorus determined by the Fiske-Subbarrow method.

Modified Bray-1, 1:50 One gram of soil was shaken with 50 ml of 0.03N NH_4F, 0.025N HCl in a 250 ml erlenmeyer flask for 2 minutes at 190 OPM. The extracts were filtered and phosphorus determined by the Fiske-Subbarrow method.

Olsen test (36) A two-gram soil sample was shaken with 40 ml of 0.5N $NaHCO_3$ adjusted to a pH of 8.5 with NaOH. The extraction was conducted in a 125 ml erlenmeyer flask at 190 OPM for 30 minutes. The extracts were filtered and phosphorus in solution was measured by the ascorbic acid method (58).

Water soluble phosphorus A five-gram soil sample was shaken with 50 ml of deionized water in a 125 ml erlenmeyer flask for one hour at 190 OPM. Solutions were centrifuged and filtered until clear. Phosphorus was determined by the ascorbic acid method using 2.5 cm diameter cell in a Spec 20 colorimeter.

Phosphorus sorption index (3) A five-gram soil sample was equilibrated with 100 ml of 0.0175M KCl, 0.0025M KH_2PO_4 for 18 hours in a 250 ml erlenmeyer flask at 200 OPM. Solutions were then centrifuged and filtered until clear. Phosphorus remaining in the equilibrium solution was determined by the Fiske-Subbarrow method (26). The difference between the amount of phosphorus in solution before and after equilibration was assumed to be the phosphorus sorbed by the soil. The index was computed as follows:

$$\text{Index} = \frac{\text{micromoles P sorbed}}{\text{100 grams soil}} \div \begin{array}{c}\text{log of equilibrium}\\ \text{P concentration}\end{array}$$

Statistical Methods

Small grain phosphorus yield responses were related to various soil tests through linear regression and correlation analysis. Stepwise multiple regression analysis employing dummy variables was used to examine the effects of classification categories on prediction of P yield response. The *Statistical Package for the Social Sciences* was the source of the computer programs (32). "F" and "t" tests were conducted according to Steel and Torrie (51).

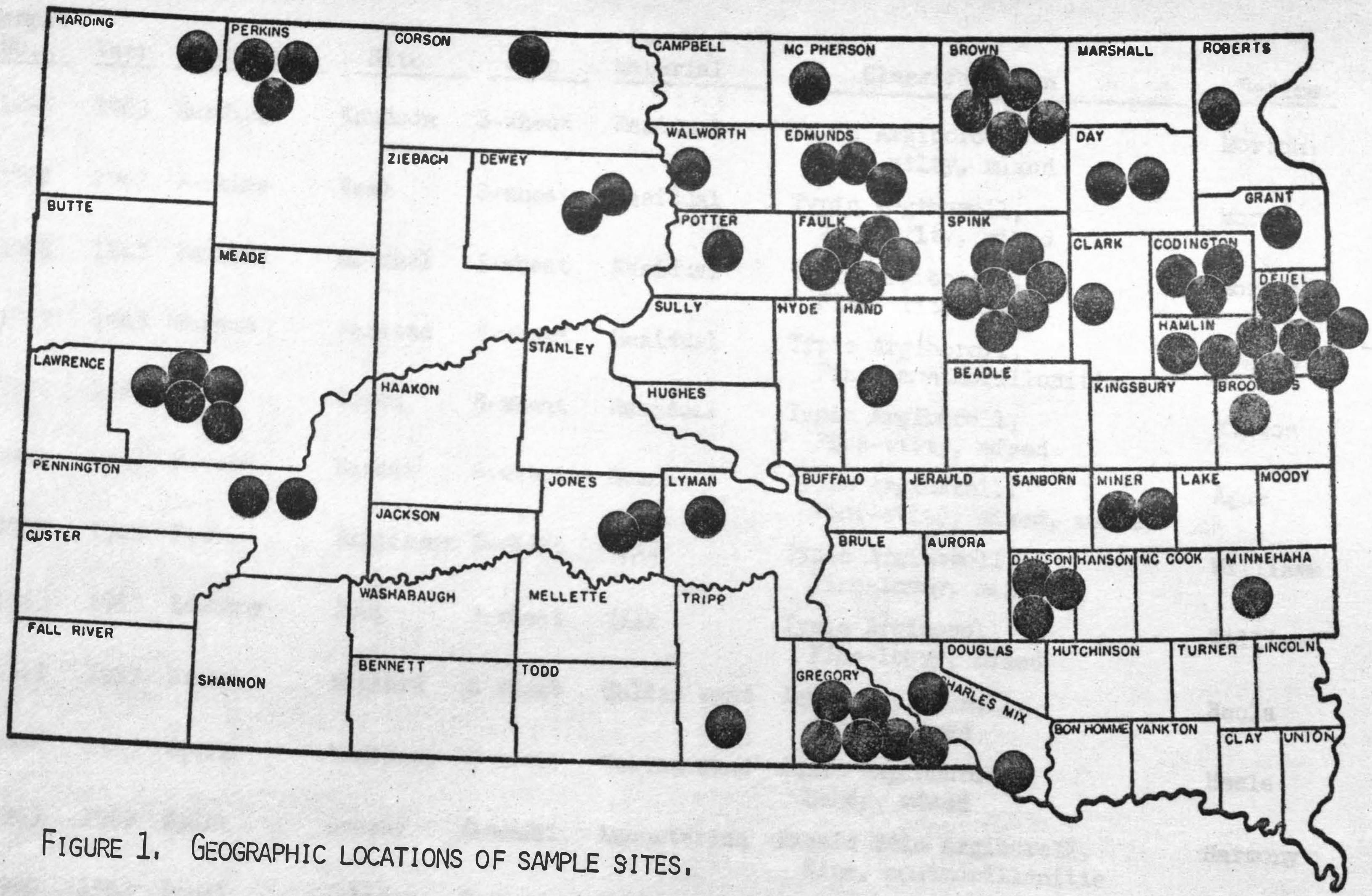

FIGURE 1. GEOGRAPHIC LOCATIONS OF SAMPLE SITES.

Table 2. Experimental year, location, crop species, parent material, and classification of soils in the study.

Sample No.	Year	County	Site	Crop	Parent Material	Classification	Series
1898	1963	Harding	Knudson	S-wheat	Residual	Typic Argiboroll, Fine-silty, mixed	Morton
1902	1963	Perkins	Veal	S-wheat	Residual	Typic Argiboroll, Fine-silty, mixed	Morton
1908	1963	Perkins	Mitchel	S-wheat	Residual	Typic Argiboroll, Fine-silty, mixed	Morton
1917	1963	Corson	Farstad	S-wheat	Residual	Typic Argiboroll, Fine, montmorillonitic	Regent
1921	1963	Dewey	Dosch	S-wheat	Residual	Typic Argiboroll, Fine-silty, mixed	Morton
1931	1963	Potter	Nauman	S-wheat	Loess	Typic Argiustoll, Fine-silty, mixed, mesic	Agar
1937	1963	Faulk	Bergerson	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams
1943	1963	Edmunds	Jung	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams
1948	1963	Brown	Nygaard	S-wheat	Eolian sand	Aquic Haploboroll, Sandy, mixed	Hecla
1958	1963	Spink	VanVleet	S-wheat	Eolian sand	Aquic Haploboroll, Sandy, mixed	Hecla
1963	1963	Spink	Overby	S-wheat	Lacusterine	Pachic Udic Argiboroll, Fine, montmorillonitic	Harmony
1980	1963	Deuel	Johnson	Barley	Till	Udic Haploboroll, Fine-loamy, mixed	Vienna

Table 2. Continued.

Sample No.	Year	County	Site	Crop	Parent Material	Classification	Series
2611	1964	Spink	Schween	S-wheat	Till	Typic Argiustoll, Fine-loamy, mixed, mesic	Houdek
2623	1964	Faulk	Bergerson	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams
2658	1964	Gregory	Norberg	S-wheat	Loess	Typic Argiustoll, Fine, montmorillonitic, mesic	Reliance
2668	1964	Miner	Walter	Oats	Till	Pachic Haplustoll, Fine-loamy, mixed, mesic	Bonilla
2678	1964	Charles Mix	McGuire	S-wheat	Loess	Typic Argiustoll, Fine, montmorillonitic, mesic	Reliance
2690	1964	Gregory	Cerny	Oats	Eolian sand	Typic Haplustoll, Coarse-loamy, mixed, mesic	Anselmo
2716	1964	Brown	Nygaard	S-wheat	Eolian sand	Aquic Haploboroll, Sandy, mixed	Hecla
2723	1964	Brown	Ruden	S-wheat	Lacusterine	Udic Haploboroll, Fine-silty, mixed	Great Bend
3150	1965	Gregory	Warnke	Barley	Loess	Typic Argiustoll, Fine, montmorillonitic, mesic	Reliance
3155	1965	Charles Mix	Uherka	Barley	Loess	Typic Argiustoll, Fine, montmorillonitic, mesic	Reliance
3159	1965	Spink	Dumis	Barley	Lacusterine	Pachic Udic Haploboroll, Fine-silty, mixed	Beotia

Table 2. Continued.

Sample No.	Year	County	Site	Crop	Parent Material	Classification	Series
3164	1965	Miner	Walter	Oats	Till	Typic Argiustoll, Fine-loamy, mixed, mesic	Houdek
3217	1965	Edmunds	Volk	S-wheat	Till	Typic Argiustoll, Fine-loamy, mixed, mesic	Houdek
3222	1965	Spink	Schween	S-wheat	Till	Typic Argiustoll, Fine-loamy, mixed, mesic	Houdek
3226	1965	Brown	Wright	S-wheat	Alluvium	Aquic Haploboroll, Sandy, mixed	Hecla
3237	1965	Day	Dedrickson	S-wheat	Till	Udic Haploboroll, Fine-loamy, mixed	Barnes
3494	1966	Tripp	Fischer	Oats	Residual	Vertic Argiustoll, Fine, montmorillonitic, mesic	Millboro
3543	1966	Spink	Golden	S-wheat	Lacusterine	Pachic Udic Argiboroll, Fine, montmorillonitic	Harmony
3614	1966	Deuel	Christopherson	Barley	Till	Hapludic Vermiboroll, Fine-loamy, mixed	Singsaas
3637	1966	Edmunds	Haar	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams
3674	1966	Codington	Mack	Barley	Loess	Pachic Udic Haploboroll, Fine-silty, mixed	Brookings
4016	1967	Codington	Mack	Barley	Loess	Pachic Udic Haploboroll, Fine-silty, mixed	Brookings
4070	1967	Deuel	Peterson	Barley	Till	Hapludic Vermiboroll, Fine-loamy, mixed	Singsaas

Table 2. Continued.

Sample No.	Year	County	Site	Crop	Parent Material	Classification	Series
4098	1967	Faulk	PRC	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams
5002	1967	Day	Bohn	S-wheat	Lacusterine	Pachic Udic Haploboroll, Fine, montmorillonitic	Sinai
5116	1968	Meade	Komes	W-wheat	Alluvium	Aridic Argiustoll, Fine, mixed, mesic	Savo
5121	1968	Pennington	Kitterman	W-wheat	Residual	Typic Argiboroll, Fine-silty, mixed	Morton
5131	1968	Faulk	PRC	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams
5136	1968	Hand	Gerdes	S-wheat	Till	Typic Argiustoll, Fine-loamy, mixed, mesic	Houdek
5141a	1968	Davison	Strand	Oats	Till	Typic Haplustoll, Fine-loamy, mixed, mesic	Clarno
5141b	1968	Davison	Strand	S-wheat	Till	Typic Haplustoll, Fine-loamy, mixed, mesic	Clarno
5141c	1968	Davison	Strand	Barley	Till	Typic Haplustoll, Fine-loamy, mixed, mesic	Clarno
5156	1968	Codington	Mack	Barley	Loess	Pachic Udic Haploboroll, Fine-silty, mixed	Brookings
5173	1968	Hamlin	Bevers	S-wheat	Till	Udic Haploboroll, Fine-silty, mixed	Poinsett
5177	1968	Faulk	PRC	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams

Table 2. Continued.

Sample No.	Year	County	Site	Crop	Parent Material	Classification	Series
5735	1969	Meade	Keffler	W-wheat	Alluvium	Aridic Argiustoll, Fine, mixed, mesic	Savo
5740	1969	Meade	Bachand	W-wheat	Alluvium	Aridic Argiustoll, Fine, mixed, mesic	Savo
6002	1969	Jones	Roghair	W-wheat	Loess	Typic Argiustoll, Fine, montmorillonitic, mesic	Reliance
6007	1969	Pennington	Kitterman	W-wheat	Residual	Typic Argiboroll, Fine-silty, mixed	Morton
6364	1970	Meade	Bachand	W-wheat	Alluvium	Aridic Argiustoll, Fine, mixed, mesic	Savo
6379	1970	Jones	Roghair	W-wheat	Residual	Vertic Haplustoll, Very fine, montmorillonitic, mesic	Opal
7282	1970	Minnehaha	Otherby	Oats	Loess	Udic Haplustoll, Fine-silty, mixed, mesic	Moody
7299	1970	Brookings	Colborn	Barley	Loess	Udic Haploboroll, Fine-silty, mixed	Kranzburg
7320	1970	Grant	Kneeland	S-wheat	Till	Udic Haploboroll, Fine-loamy, mixed	Vienna
13216	1973	McPherson	Eureka	S-wheat	Till	Typic Argiboroll, Fine-loamy, mixed	Williams
13410	1973	Perkins	Bison	S-wheat	Residual	Typic Argiboroll, Fine-silty, mixed	Morton

Table 2. Continued

Sample No.	Year	County	Site	Crop	Parent Material	Classification	Series
13427	1973	Spink	Styles	S-wheat	Lacusterine	Pachic Udic Argiboroll, Fine, montmorillonitic	Harmony
13435	1973	Meade	Hereford	S-wheat	Alluvium	Aridic Argiustoll, Fine-loamy, mixed, mesic	Satanta
13515	1973	Walworth	Selby	S-wheat	Loess	Typic Argiustoll, Fine-silty, mixed, mesic	Agar
16973-86	1974	Clark	Neuberger	S-wheat	Till	Udic Haploboroll, Fine-silty, mixed	Poinsett
17002-17	1974	Brown	Scharnock	S-wheat	Lacusterine	Pachic Udic Haploboroll, Fine-silty, mixed	Beotia
17042-57	1974	Dewey	Stanley	S-wheat	Residual	Vertic Haplustoll, Very fine, montmorillonitic, mesic	Opal
17062-76	1974	Roberts	Weeks	S-wheat	Till	Aeric Calciaquoll, Coarse-loamy, frigid	Fram
17116	1974	Hamlin	Bevers	S-wheat	Till	Udic Haploboroll, Fine-silty, mixed	Poinsett
19880a	1975	Gregory	Eide	S-wheat	Eolian sand	Typic Haplustoll, Coarse-loamy, mixed, mesic	Anselmo
19880b	1975	Gregory	Eide	Oats	Eolian sand	Typic Haplustoll, Coarse-loamy, mixed, mesic	Anselmo
19880c	1975	Gregory	Eide	Barley	Eolian sand	Typic Haplustoll, Coarse-loamy, mixed, mesic	Anselmo

Table 2. Continued.

Sample No.	Year	County	Site	Crop	Parent Material	Classification	Series
20012	1975	Lyman	Anderson	S-wheat	Residual	Vertic Haplustoll, Very fine, montmorillonitic, mesic	Promise
20038a	1975	Deuel	Knox	S-wheat	Till	Udic Haploboroll, Fine-loamy, mixed	Vienna
20038b	1975	Deuel	Knox	Barley	Till	Udic Haploboroll, Fine-loamy, mixed	Vienna
20038c	1975	Deuel	Knox	S-wheat	Till	Udic Haploboroll, Fine-loamy, mixed	Vienna
20038d	1975	Deuel	Knox	Oats	Till	Udic Haploboroll, Fine-loamy, mixed	Vienna
PI-PV	1973	Clay	S.E. Farm	--	Till	Pachic Haplustoll, Fine-silty, mixed, mesic	Viborg

RESULTS AND DISCUSSION

Field experiments involving phosphorus fertilization of small grains were used to evaluate the effectiveness of several soil tests in predicting yield response to P fertilization. The results of the study are discussed under three sections. In the first section, results of soil tests are reported and simple correlations between them are discussed. The effect of P fertilization on soil tests is also examined.

Section two includes a discussion on the relationship between soil tests and yield increase from P fertilization. In the third section, the effect of various factors on the relationship between soil tests and yield increase from P fertilization is examined.

Results of Soil Tests

The results of soil tests from 74 small grain experiments included in the study are reported in Table 3. The last five samples in the table, PI through PV, represent five P treatments of a phosphorus residual experiment where the indicated applications of P fertilizer were made.

Table 4 contains the simple correlation coefficients between ten variables related to P status. A high correlation existed between all four of the Bray P tests. The 1:50 showed a lower correlation with the other Bray tests indicating that all samples were not releasing an equivalent additional amount of P at this higher soil to solution ratio. The Olsen test was most highly correlated with the Bray 1:20. This may be due to the equal soil to solution ratio

Table 3. Yield and soil test results.

Sample No.	Texture Class	% O.M.	pH	Yield			Modified Bray P				Olsen P	Water Soluble P	P Sorption Index
				Check Kg/ha	(bu/A)	% Increase*	1:7 pp2m	1:10 pp2m	1:20 pp2m	1:50 pp2m	pp2m	pp2m	
1898	SiCl	1.6	6.6	1350	(20)	20	25	28	39	47	24	2.2	164
1902	Sil	1.2	6.8	809	(12)	17	35	38	45	66	26	3.8	115
1908	l	1.1	6.4	877	(13)	31	28	32	41	54	22	2.9	135
1917	SiCl	2.3	6.5	1280	(19)	32	39	46	59	82	34	7.0	140
1921	Sil	1.7	6.8	540	(8)	50	27	34	42	62	25	3.5	164
1931	Sil	2.7	6.6	877	(13)	8	29	32	44	59	28	4.8	134
1937	l	2.7	6.9	675	(10)	50	35	37	46	62	31	5.6	96
1943	l	2.8	7.0	1080	(16)	38	36	42	57	78	36	5.9	174
1948	Sl	1.7	7.6	944	(14)	71	13	14	17	32	14	3.7	0
1958	Sl	1.4	6.3	809	(12)	25	21	25	36	46	18	5.5	0
1963	SiCl	4.1	6.6	540	(8)	50	35	44	50	72	34	6.8	115
1980	l	4.0	8.0	1080	(20)	45	6	7	22	40	21	2.9	273
2611	l	2.0	6.2	877	(13)	16	22	26	32	50	20	2.3	125
2623	l	2.9	6.6	675	(10)	50	29	36	42	60	24	3.5	115
2658	SiCl	3.0	6.9	1619	(24)	8	35	40	49	75	30	2.7	254
2668	l	2.7	6.7	612	(17)	17	24	30	35	54	26	3.8	96
2678	SiCl	2.8	6.8	472	(7)	29	22	29	34	48	24	2.8	144
2690	Sl	1.3	6.6	1150	(32)	19	29	34	36	58	24	4.0	67
2716	Sl	1.6	7.3	809	(12)	51	12	16	21	31	17	4.1	-29
2723	Sil	3.2	6.7	809	(12)	42	25	19	36	54	23	4.9	67

Table 3. Continued.

Sample No.	Texture Class	% O.M.	pH	Yield Check Kg/ha	Yield Check (bu/A)	Yield % Increase*	Modified Bray P 1:7 pp2m	Modified Bray P 1:10 pp2m	Modified Bray P 1:20 pp2m	Modified Bray P 1:50 pp2m	Olsen P pp2m	Water Soluble P pp2m	P Sorption Index
3150	SiCl	1.8	6.2	2100	(39)	48	30	46	50	75	28	2.5	263
3155	SiCl	2.5	6.9	2270	(42)	14	23	31	39	54	25	2.7	194
3159	Sil	3.0	6.7	1730	(32)	16	25	29	36	47	23	4.9	106
3164	l	3.5	6.6	2520	(70)	23	24	28	35	44	24	3.5	125
3217	l	3.0	6.9	1480	(22)	46	21	27	32	40	20	3.5	96
3222	l	2.6	6.4	1750	(26)	11	47	58	68	86	34	9.2	86
3226	Sl	1.5	7.0	1690	(25)	16	33	35	43	62	25	11.1	-66
3237	l	4.1	7.5	2090	(31)	39	16	17	27	41	22	3.7	294
3494	C	5.1	7.8	1040	(29)	10	39	54	77	157	55	7.6	334
3543	SiCl	3.9	7.5	540	(8)	25	37	43	58	84	30	7.5	106
3614	Sil	4.9	6.5	2540	(47)	21	25	28	40	68	22	1.9	406
3637	l	2.6	7.1	944	(14)	28	13	12	22	40	14	1.0	174
3674	Sil	3.6	7.0	1130	(21)	66	29	36	42	72	27	2.3	354
4016	SiCl	3.4	7.2	3450	(64)	6	25	30	38	61	28	2.5	283
4070	Sil	3.5	6.5	2750	(51)	63	20	24	31	56	23	1.6	243
4098	l	2.2	6.7	2360	(35)	17	16	18	25	46	18	1.1	283
5002	SiCl	3.5	7.4	2360	(35)	48	17	20	24	48	22	2.5	224
5116	SiC	1.9	7.3	2090	(31)	23	32	49	62	129	34	2.4	304
5121	Sil	1.9	6.9	2560	(38)	11	33	44	46	83	26	3.6	125

Table 3. Continued.

Sample No.	Texture Class	% O.M.	pH	Yield Check Kg/ha	Yield Check (bu/A)	Yield % Increase*	Modified Bray P 1:7 pp2m	Modified Bray P 1:10 pp2m	Modified Bray P 1:20 pp2m	Modified Bray P 1:50 pp2m	Olsen P pp2m	Water Soluble P pp2m	P Sorption Index
5131	l	2.8	6.6	1690	(25)	28	18	24	31	60	20	1.3	334
5136	Sil	3.1	6.6	2290	(34)	6	39	26	55	86	32	5.2	174
5141a	Sil	2.3	7.1	971	(27)	7	21	29	32	69	23	2.2	213
5141b	Sil	2.3	7.1	1150	(17)	8	21	29	32	69	23	2.2	213
5141c	Sil	2.3	7.1	917	(17)	25	21	29	32	69	23	2.2	213
5156	SiCl	3.7	7.1	2320	(43)	28	22	27	35	54	25	2.7	283
5173	Sil	4.2	7.4	2020	(30)	34	16	20	27	41	22	2.4	125
5177	l	3.2	6.6	1690	(25)	16	22	26	33	46	22	3.3	233
5735	C	2.8	7.2	1690	(25)	4	32	46	61	116	37	1.6	598
5740	Cl	2.4	6.5	2430	(36)	3	42	49	59	114	34	3.7	194
6002	SiCl	2.6	6.2	1750	(26)	-4	92	104	119	180	60	14.3	144
6007	Sil	1.7	6.6	1350	(20)	25	32	33	40	75	24	3.5	154
6364	SiCl	1.2	7.7	1620	(24)	21	19	23	33	54	24	1.1	283
6379	C	1.8	8.2	1550	(23)	26	8	15	24	70	19	0.6	479
7282	Sil	2.4	7.0	3850	(107)	24	29	34	42	66	24	2.1	303
7299	Sil	3.1	6.8	1620	(30)	50	16	19	25	48	20	3.1	154
7320	l	4.5	6.5	1820	(27)	22	25	31	40	65	24	4.2	164
13216	SiCl	3.1	7.7	337	(5)	33	9	12	18	30	16	1.8	233
13410	SiCl	2.5	6.7	2560	(38)	5	34	40	54	90	28	3.6	184
13427	SiCl	4.1	6.6	1690	(25)	12	37	44	57	92	33	6.6	115

Table 3. Continued

Sample	Texture	%		Yield			Modified Bray P				Olsen	Water	P
				Check		% In-	1:7	1:10	1:20	1:50	P	Soluble P	Sorption
No.	Class	O.M.	pH	Kg/ha	(bu/A)	crease*	pp2m	pp2m	pp2m	pp2m	pp2m	pp2m	Index
13435	Sil	2.6	6.5	1420	(21)	5	43	51	66	102	31	3.6	174
13515	SiCl	2.7	7.8	1420	(41)	9	11	16	21	52	17	1.1	253
16973-86	Sil	3.6	7.3	877	(13)	39	15	18	26	52	10	1.1	216
17002-17	SiCl	4.2	7.5	877	(13)	38	12	14	20	41	18	2.5	111
17042-57	Cl	3.0	6.9	472	(7)	43	19	24	30	61	19	1.6	226
17062-76	Sl	2.6	8.1	1280	(19)	32	8	16	25	40	16	0.9	253
17116	SiCl	4.3	7.3	3850	(57)	21	18	20	31	57	24	2.1	253
19880a	Sl	2.2	6.0	1080	(16)	12	33	35	42	68	23	3.8	106
19880b	Sl	2.2	6.0	1260	(35)	10	33	35	42	68	23	3.8	106
19880c	Sl	2.2	6.0	1460	(27)	28	33	35	42	68	23	3.8	106
20012	C	3.0	7.7	1420	(21)	7	10	28	47	126	29	2.9	448
20038a	l	3.4	7.1	1510	(28)	15	14	16	24	54	19	1.4	324
20038b	l	3.4	7.1	3580	(53)	19	14	16	24	54	19	1.4	324
20038c	l	3.4	7.1	2160	(32)	24	14	16	24	54	19	1.4	324
20038d	l	3.4	7.1	1980	(55)	25	14	16	24	54	19	1.4	324
	P applied (Kg/ha)												
PI		0					12	18	22	50	17	1.3	253
PII		45					27	34	43	76	26	24	253
PIII		90					40	48	61	98	34	3.8	224

Table 3. Continued.

Sample No.	Texture Class	% O.M.	pH	Yield Check Kg/ha	Yield Check (bu/A)	Yield % In-crease*	Modified Bray P 1:7 pp2m	Modified Bray P 1:10 pp2m	Modified Bray P 1:20 pp2m	Modified Bray P 1:50 pp2m	Olsen P pp2m	Water Soluble P pp2m	P Sorption Index
	P applied (Kg/ha)												
PIV	180						60	68	84	123	49	5.2	243
PV	360						122	129	156	232	77	15.2	224

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* Percent yield increase from P fertilization over the check yield. Calculated as

$$\left(\frac{\text{yield with P} - \text{yield without P}}{\text{yield without P}}\right)100.$$

Table 4. Simple correlation coefficients between soil tests.

Independent Variable	Description	Independent Variables								
		2	3	4	5	6	7	8	9	10
1	Modified Bray, 1:7	.950**	.935**	.733**	.833**	.766**	-.242*	-.548**	.146	-.155
2	Modified Bray, 1:10		.960**	.823**	.876**	.707**	-.113	-.448**	.276*	-.120
3	Modified Bray, 1:20			.884**	.928**	.723**	-.035	-.374**	.346**	-.028
4	Modified Bray, 1:50				.869**	.496**	.260*	-.130	.505**	.042
5	Olsen P					.686**	.070	-.198	.484**	.126
6	Water Soluble P						-.512**	-.311**	-.002	-.001
7	P Sorption Index							.400**	.511**	.307**
8	pH								.336**	.233*
9	Texture+									.173
10	Organic matter									1.000

+ Increasing texture refers to increasing fineness

* Significant at .05 level

** Significant at .01 level

of these two tests. All P soil tests were correlated with water soluble P.

The negative correlation between the Bray 1:7 and pH is apparently due partially to neutralization of the HCl in the Bray extracting solution by $CaCO_3$. As the pH increased, $CaCO_3$ increased. This was verified by observing CO_2 evolution when HCl was added to the soil. The $CaCO_3$ caused neutralization of the acid in the extracting solution and decreased the dissolution of calcium phosphates in the soil. This relationship has been found in several instances where calcareous soils were involved. (4,50,44) Also, Randall and Grava (44) reported that during extraction, calcium may be complexing the fluoride ion as CaF_2. Therefore, complexing of the fluoride and neutralization of the dilute HCl by carbonate may have caused the negative correlation between pH and Bray 1:7 P.

This effect of pH on Bray extractable P decreased as the soil to solution ratio increased. Since more acid and fluoride were present per gram of soil in the wider dilutions, especially the 1:50, the $CaCO_3$ was not sufficient to neutralize the extracting solution and the influence of pH on extracted P became minimal.

The lack of correlation between pH and Olsen P was likely due to the extracting solution. This soil test uses $NaHCO_3$, a basic extracting solution, which theoretically should not have been affected by $CaCO_3$ content. This agrees with the findings of Blanchar and Caldwell (4) but does not agree with Westin and Buntley (61) who reported a negative correlation between pH and Olsen P for several

Chestnut soils.

A constantly increasing positive correlation between Bray extractable P and texture was found as the soil to solution ratio increased. A positive correlation was noted between texture and pH and between texture and sorption index. Thus, as texture became finer, pH increased and more $CaCO_3$ was probably present but at the same time the P sorption of the soil increased and more P may have been present for potential extraction.

The presence of extra $CaCO_3$ in the finer-textured soils prevented the Bray solution with narrower soil to solution ratios from extracting the P sorbed on the clay. As the soil to solution ratio increased, sufficient HCl and NH_4F was present to dissolve the $CaCO_3$, as well as extract the additional P present in the finer-textured soils. This resulted in the increasing positive correlation between texture and Bray extractable P as the soil to solution ratio increased.

The positive correlation between Olsen P and texture adds support to the preceding explanation. Theoretically, $NaHCO_3$ extractable P should not be influenced by $CaCO_3$. Thus, the Olsen test should show a positive correlation with texture if, in fact, more sorbed P is present in the finer-textured soils.

The P sorption index was positively correlated with both texture and organic matter. This indicates that P sorption sites are located in both the inorganic clay fraction and in organic matter in these soils. This supports the data from a study of soils from 11 states conducted by Vijayachandran and Harter (12).

As the P sorption index increased, water soluble P decreased. In soils with greater P sorption ability, P was likely more strongly sorbed on adsorption sites rather than in forms readily water soluble. Also, the P sorption index was calculated by difference between the initial P concentration and the equilibrium P concentration. Therefore, as water soluble P increased, the equilibrium P concentration would also increase. This would cause a smaller difference between initial and equilibrium concentrations and thus decrease the P sorption index somewhat. Since the amount of water soluble P was small relative to the amount of P sorbed for most soils, this second factor was likely of minor significance.

The influence of P fertilization on soil test values was examined at one location. The soil tests from this experiment are not included in the correlation matrix of Table 4. The P fertilizer was applied as treble superphosphate in 1964-67 and soil samples taken in 1973. Figure 2 shows the linear regression equations, lines, and r^2 values between the soil tests and applied P. All soil P tests responded quite favorably to P fertilization, and all had r^2 values of approximately .99 with the exception of water soluble P. If the last treatment, 360 Kg/ha, is not included in the regression equation for water soluble P, the r^2 value increases to .98. Figure 3 shows the resulting line and equation.

It is the opinion of the author that at this higher level of P fertilization, the relationship between added fertilizer P and water soluble P is no longer linear but rather curvilinear and the proposed

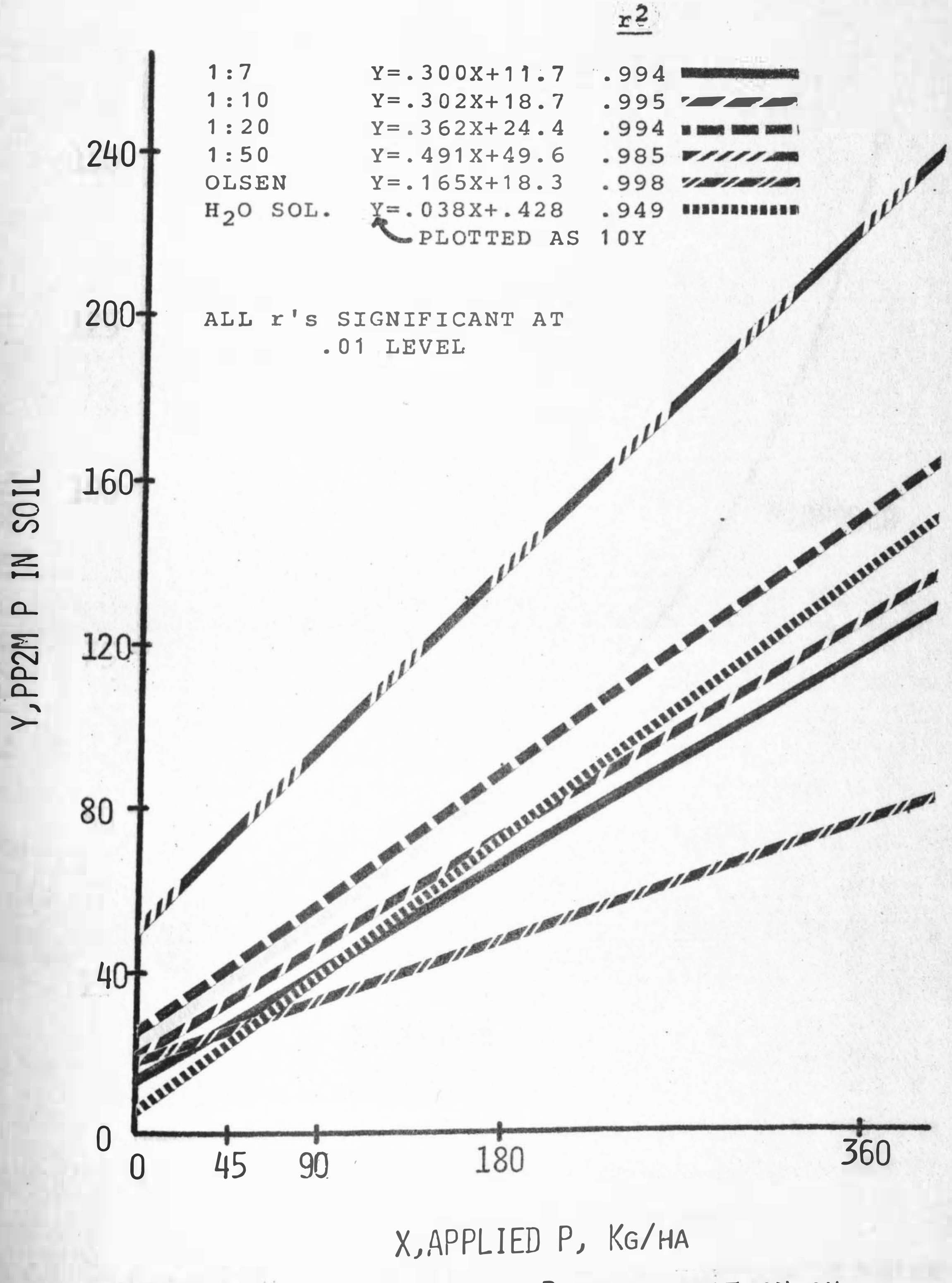

FIGURE 2. THE EFFECT OF P FERTILIZATION ON SOIL TESTS.

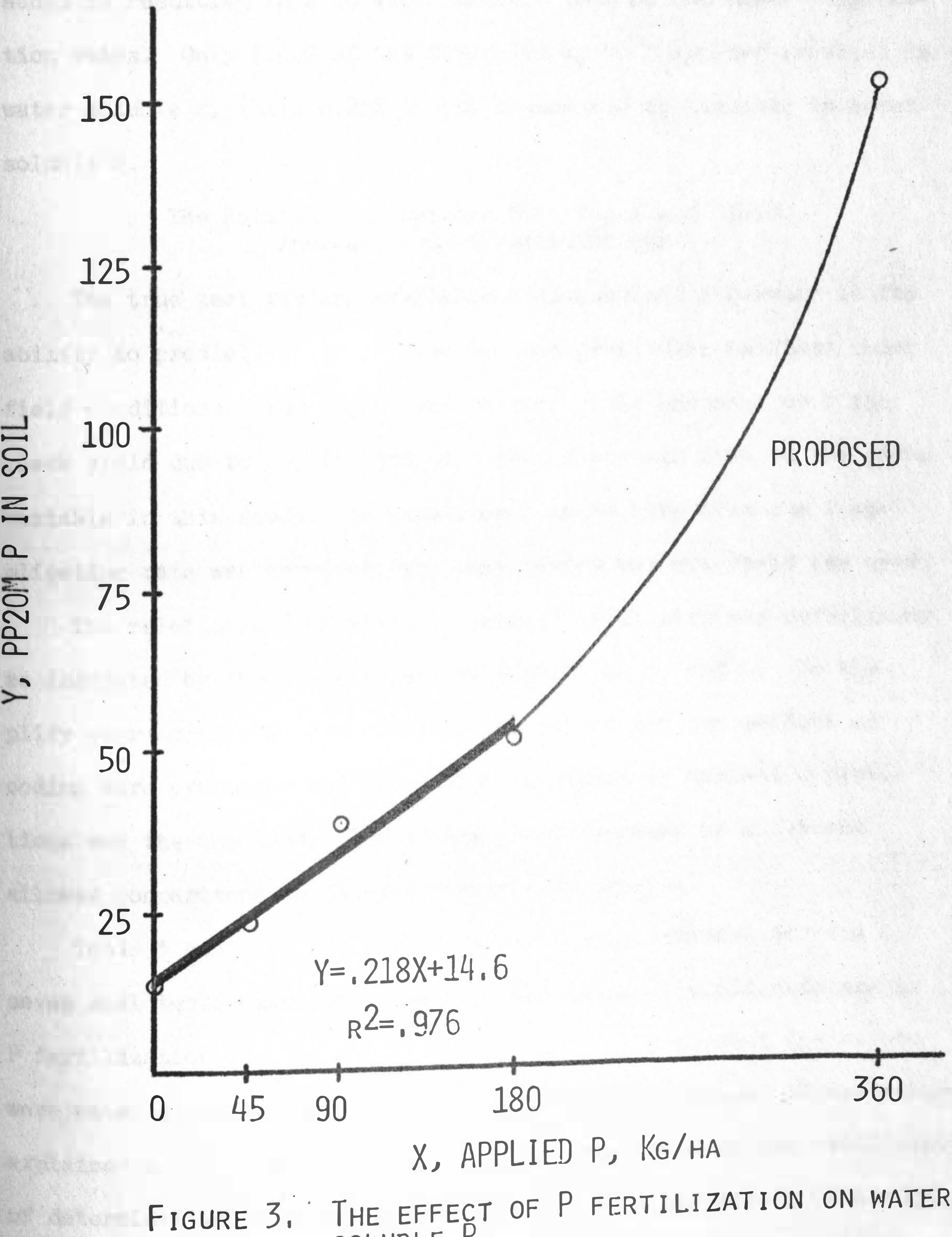

FIGURE 3. THE EFFECT OF P FERTILIZATION ON WATER SOLUBLE P.

curve in Figure 3 results. This means that more of the fertilizer P added is resulting in P in water soluble form at the higher application rates. Only 2.44% of the first 180 Kg of P applied resulted in water soluble P, while 6.25% of the second 180 Kg resulted in water soluble P.

The Relationship Between Soil Tests and Yield Increase from P Fertilization

The true test for any available soil nutrient parameter is its ability to predict yield response to that particular nutrient under field conditions. The log of the percent yield increase over the check yield due to application of P fertilizer was used as the yield variable in this study. In experiments where more than one P application rate was involved, the rate giving maximum yield was used.

The relationship of yield increase to soil test was curvilinear as indicated by the scattergrams in Figures 4, 5, and 6. To simplify regression analysis and interpretation, various methods of coding were evaluated and the method resulting in highest correlations was the one used. Expressing yield increase as a percent allowed comparisons to be made across crop species.

Table 5 contains the simple regression information for the seven soil tests examined. The best indicator of yield response to P fertilization was the Modified Bray 1:50. The poorest indicators were water soluble P and the sorption index. The amount of variation explained by the independent variable, as expressed by the coefficient of determination (r^2), continually increased as the soil to solution ratio of the Bray tests increased. The Modified Bray 1·50 explained

12% more of the variation in yield than did the Modified Bray 1:7.

The Olsen test did not explain more of the variation in yield response than did the Modified Bray 1:7. J. C. Zubriski (66), in a study of North Dakota soils, and R. A. Olsen and others (34), in a study of Nebraskan soils, found similar results on calcareous and noncalcareous soils.

Since the amount of variation explained by the soil test alone, especially the Bray 1:7 or Olsen tests, is quite low, information such as that recorded in Table 6 may be valuable. The table indicates that with a Bray 1:7 test of 31-40 pp2m, 47% of the experiments had less than a 15% yield increase. With a Bray 1:50 test of 71-90 pp2m, 42% of the experiments had less than a 15% yield increase.

Table 5. Simple regression equations between soil tests, X, and log of the percent yield increase from P fertilization, Y, for 74 small grain experiments.

Soil Test	Regression Equation	r[+]	r^2
Modified Bray			
1:7	Y = 1.689 - .0153 X	-.541**bc	.293
1:10	Y = 1.708 - .0134 X	-.544**bc	.296
1:20	Y = 1.799 - .0127 X	-.583**c	.340
1:50	Y = 1.849 - .0083 X	-.639**c	.408
Olsen	Y = 1.899 - .0240 X	-.535**bc	.286
Water Soluble	Y = 1.453 - .0438 X	-.295ab	.087
Sorption Index	Not Significant	-.161a	.023

[+] Correlation coefficients with the same letter are not significantly different at the .05 level according to Z test analysis.

** Correlation coefficient significant at .01 level.

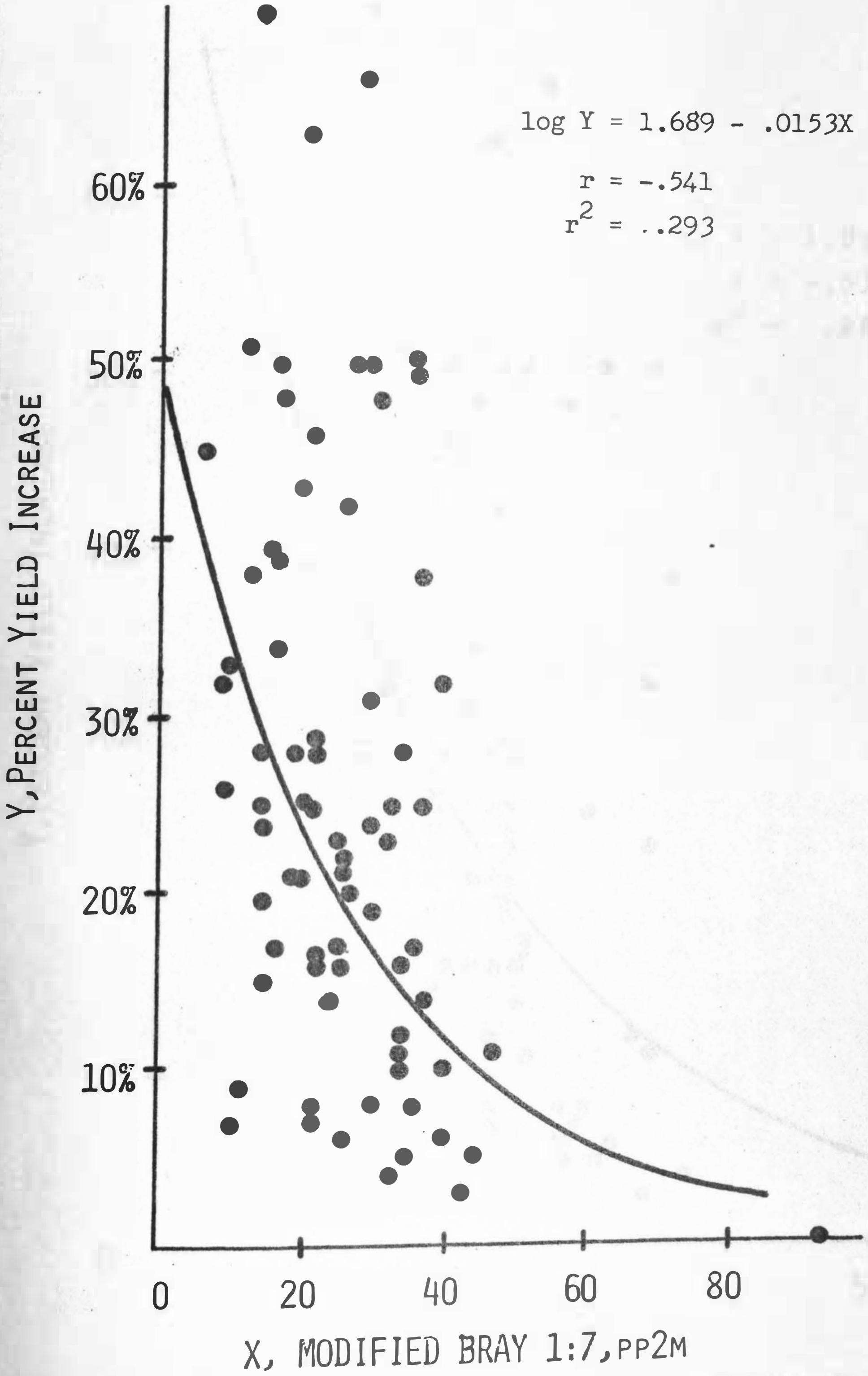

FIGURE 4. RELATIONSHIP BETWEEN MODIFIED BRAY 1.7 P AND YIELD INCREASE OVER THE CHECK FROM P FERTILIZATION.

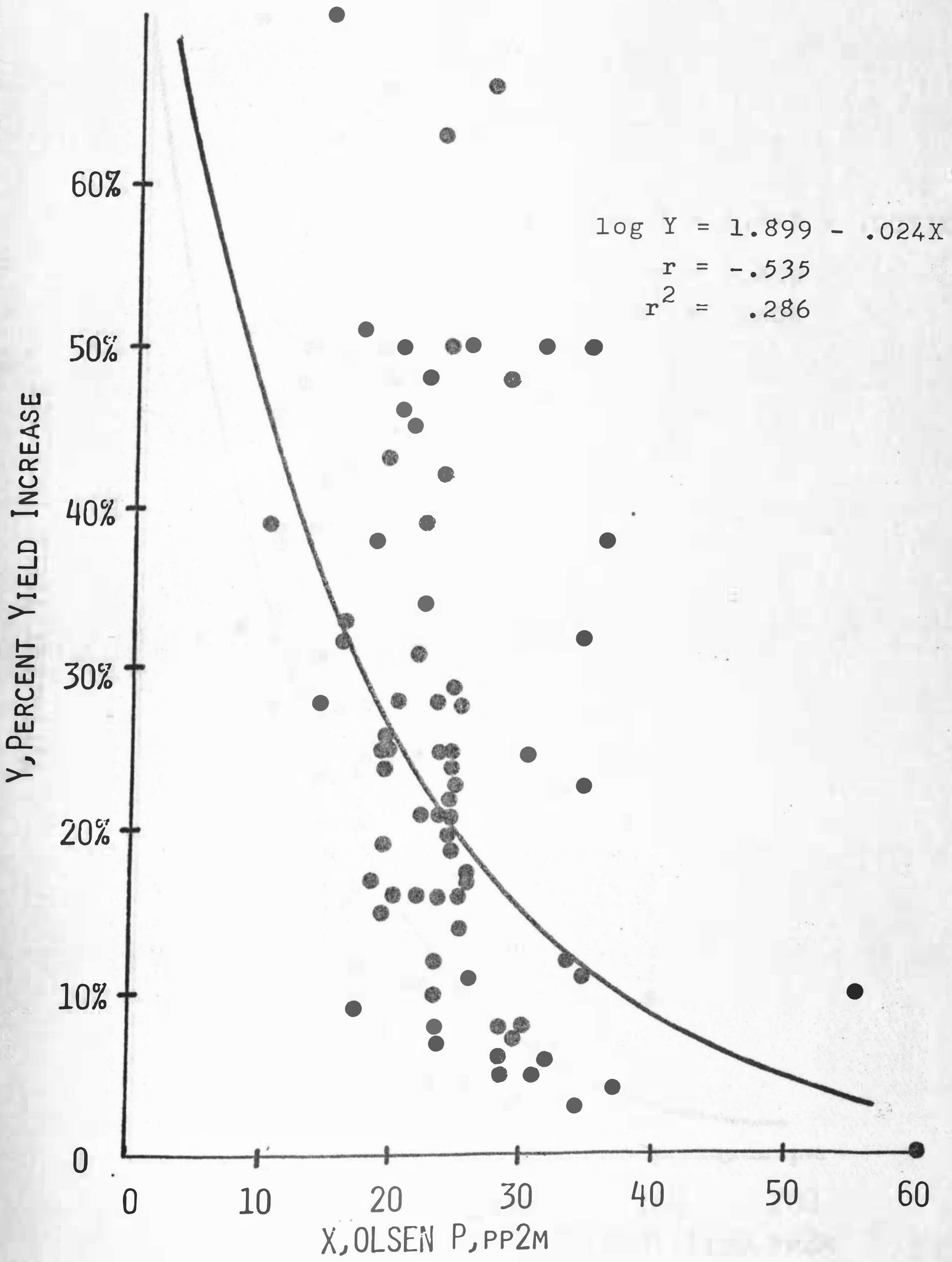

FIGURE 5. RELATIONSHIP BETWEEN OLSEN P AND YIELD INCREASE OVER THE CHECK FROM P FERTILIZATION.

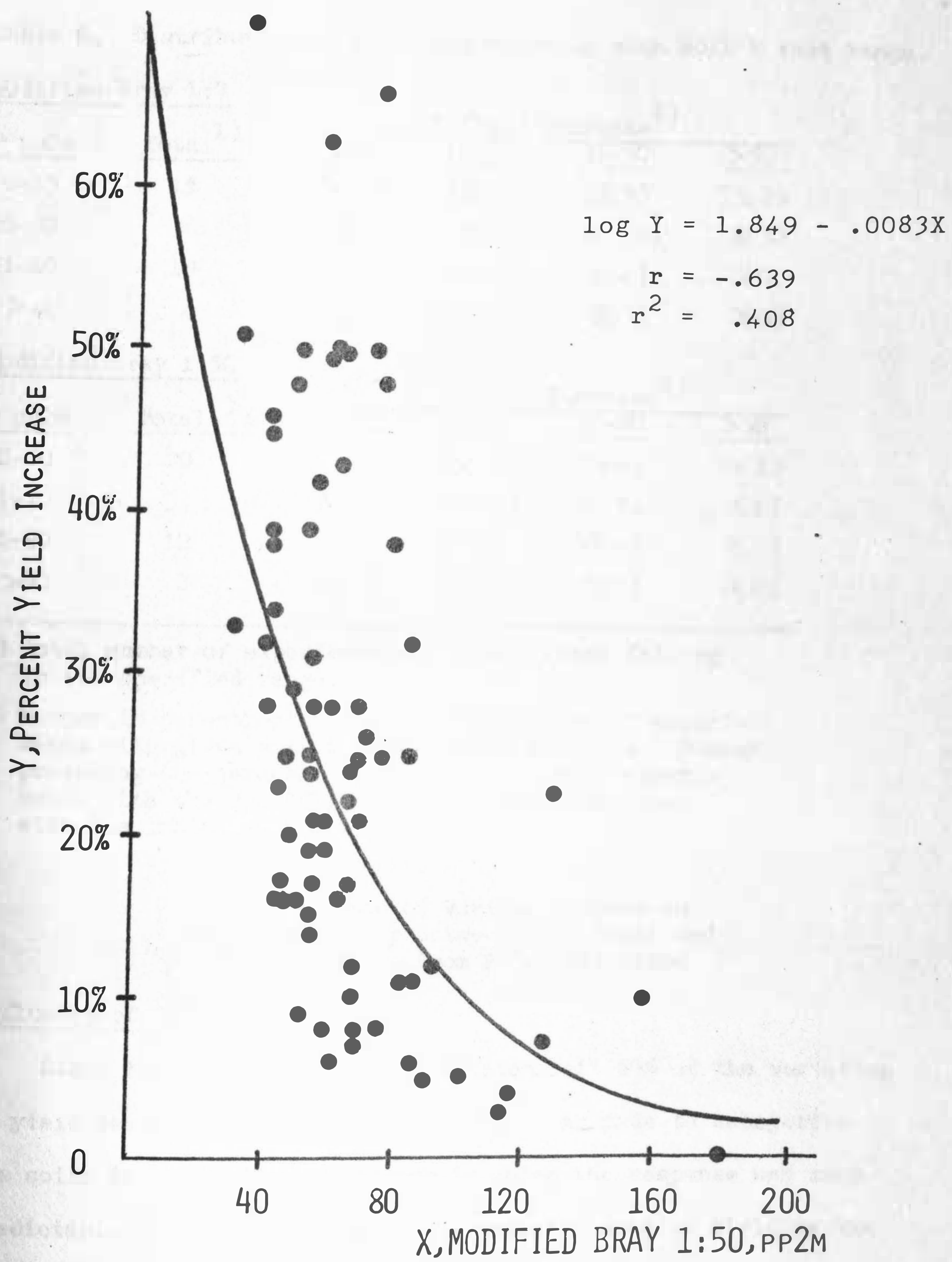

Figure 6. Relationship between Modified Bray 1:50 P and yield increase over the check from P fertilization.

Table 6. Distribution of yield increases in each soil P test range.

Modified Bray 1:7

		% Yield Increase2)			
P pp2m	Total1)	0-15	16-30	31-50	>50
0-15	15	20(3)	33(5)	33(5)	13(2)
16-30	36	14(5)	47(17)	31(11)	8(3)
31-40	19	47(9)	32(6)	21(4)	0(0)
>40	4	100(4)	0(0)	0(0)	0(0)

Modified Bray 1:50

		% Yield Increase2)			
P pp2m	Total1)	0-15	16-30	31-50	>50
0-50	20	0(0)	45(9)	45(9)	10(2)
51-70	34	26(9)	50(17)	21(7)	3(1)
71-90	12	42(5)	17(2)	33(4)	8(1)
>90	8	88(7)	12(1)	0(0)	0(0)

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1) Total number of experiments with soil tests falling in the specified range.

2) Number in parenthesis is the actual number of experiments with given soil test and yield increase. Number preceding the parenthesis is the percent of experiments with the specified soil test that responded with the indicated yield response.

The Influence of Various Factors on the Relationship Between Soil Tests and Yield Increase From P Fertilization

Influence of Climate

Since the best P soil test evaluated left 59% of the variation in yield response unexplained, an attempt was made to categorize the soils in the study into groups in which the response was more predictable. Climate was one of the criteria used in dividing the soils into more homogeneous groups. The suborder, great group, and subgroup categories of the comprehensive system of soil classification (56) were used to categorize the climate factor. The suborder and subgroup categories considered are shown on the map in Figure 7.

The influence of temperature was examined by comparing the Borolls of northern South Dakota to the Ustolls of southern South Dakota. The line separating the Borolls and Ustolls represents soils having mean annual soil temperatures of 8° C with Borolls having mean annual soil temperatures less than 8° C (56).

The influence of moisture was examined at two levels of the classification system. At the great group level, Argi was compared to Haplo. Soils of the Argi great group have developed argillic horizons. This is normally an indication of a dry soil since soil cracking must be severe enough to cause clay migration and the development of an argillic horizon. The Haplo great group specifies soils lacking an argillic horizon and, therefore, tend to be more moist.

At the subgroup level, aridic and typic were compared to udic. The udic subgroup represents soils that either receive more rainfall or runoff water than the typic subgroup. The aridic subgroup, representing an intergrade to the Aridisol order, is drier than the typic subgroup. The aridic and typic subgroups were combined in this analysis due to the few experiments conducted in the aridic area.

Table 7 contains the correlation coefficients and significance tests that resulted from grouping the soils by climatic factors. The soil tests, in general, correlated better with yield increase for

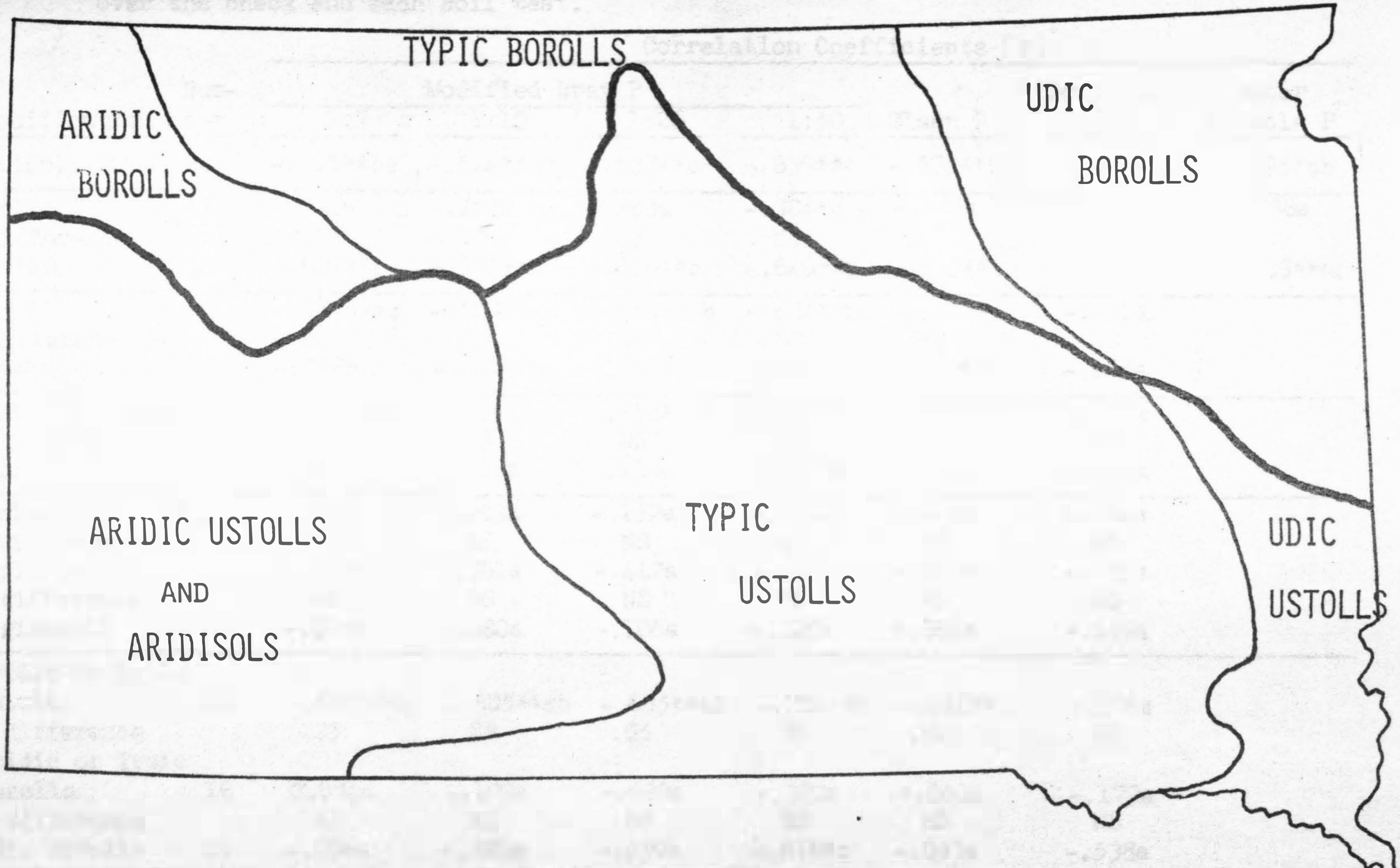

FIGURE 7. SOME SUBORDERS AND SUBGROUPS OF S.D. SOILS.

Table 7. The effects of climate as categorized by the comprehensive system of soil classification (15) on simple correlation coefficients between the log of the percent yield increase over the check and each soil test.

		Correlation Coefficients (r)$^{+}$						
		Modified Bray P						
Classification	Number	1:7	1:10	1:20	1:50	Olsen P	Sorption Index	Water Soluble P
Mollisols	74	-.541**bc	-.544**bc	-.583**c	-.639**c	-.535**bc	-.161a	-.295*ab
Borolls	43	-.252a	-.253a	-.280a	-.384*a	-.173a	-.133a	0.038a
difference		.10	.10	.05	NS	.05	NS	.05
Ustolls	30	-.627**b	-.590**b	-.656**b	-.646**b	-.630**b	-.106a	-.533**ab
Argi	38	-.587**ab	-.529**ab	-.588**ab	-.634**b	-.526**ab	-.231a	
difference		NS	NS	NS	NS	NS	NS	
Haplo	33	-.298a	-.487**a	-.508**a	-.560**a	-.487**a	-.166a	
Aridic or Typic	40	-.556**ab	-.515**ab	-.556**ab	-.659**b	-.545**ab	-.203a	
difference		NS	NS	NS	NS	NS	NS	
Udic	13	-.146a	-.266a	-.118a	-.600*a	-.129a	-.550a	
Haplustoll	11	+.165a	-.093a	-.232a	-.466a	-.416a	-.050a	
difference		NS	NS	NS	NS	NS	NS	
Haploboroll	22	-.348a	-.361a	-.412a	-.437*a	-.389a	-.180a	
difference		NS	NS	NS	NS	NS	NS	
Argiboroll	19	-.074a	-.080a	-.106a	-.329a	+.061a	-.149a	
Aridic or Typic Ustolls	24	-.667**ab	-.585**ab	-.655**ab	-.701**b	-.692**b	-.196a	
difference		.05	NS	.05	NS	.01	NS	
Aridic or Typic Borolls	16	0.074a	-.100a	-.089a	-.322a	+.060a	-.172a	
difference		NS	NS	NS	NS	NS	NS	
Udic Borolls	12	-.076a	-.229a	-.039a	-.616*a	-.093a	-.538a	
Argiustoll	19	-.740**b	-.633**ab	-.704**b	-.663**ab	-.658**ab	-.135a	
difference		.01	NS	NS	NS	NS	NS	
Haplustoll	11	+.165a	-.093a	-.232a	-.466a	-.416a	-.050a	

Table 7. Continued

Classification	Number	Correlation Coefficients (r)[+]					
		Modified Bray P					Sorption
		1:7	1:10	1:20	1:50	Olsen P	Index
Typic Argiboroll	16	-.074a	-.100a	-.089a	-.322a	+.060a	-.172a
difference		.05	NS	.05	.10	.05	NS
Typic Argiustoll	12	-.770**b	-.641*ab	-.744**b	-.815**b	-.780**b	-.007a

---

[+] Z test for difference between r's expressed as follows:

1) Correlation coefficients having the same letter across a classification category are not different at the .05 level.

2) Differences between classification categories:
   .05 correlation coefficients different at the .05 level
   .10 correlation coefficients different at the .10 level
   NS correlation coefficients not statistically different

* Correlation coefficient significant at .05 level

** Correlation coefficient significant at .01 level

Ustolls, the warmer soils, than for the cooler Boroll soils. The Bray 1:50 was the only test with a significant correlation in the Boroll group. The water soluble P test was added to this study primarily in an attempt to improve the correlation in this group. Since it did not do this, it was not included in the remaining comparisons. There was no advantage to using the Bray 1:50 rather than the 1:7 among the Ustolls, however, in the Borolls, it did increase the correlation.

The influence of temperature among the more moist soils can be evaluated by comparing the Haplustolls (moist, warm) to the Haploborolls (moist, cool). There were no significant differences between these two groups for any of the soil tests.

The influence of temperature among the drier soils can be evaluated by comparing the aridic or typic Ustolls (dry, warm) to the aridic or typic Borolls (dry, cool). The warmer soils had higher correlations than the cooler ones. No soil tests were significantly correlated with yield in the cooler group. The same basic trend appears when typic Argiustolls (dry, dry, warm) are compared to typic Argiborolls (dry, dry, cool).

The effect of moisture on soil test correlation can be evaluated by comparing Argi (dry) to Haplo (moist) and by comparing aridic or typic (dry) to udic (moist). In both comparisons, no significant differences between groups resulted, however, in all but one case, the drier group had the higher r value.

The influence of moisture among the cooler soils can be evaluated by comparing Haploborolls (moist, cool) to Argiborolls (dry, cool) and by comparing the aridic or typic Borolls (dry, cool) to the udic Borolls (moist, cool). In both comparisons, moisture did not appear to affect soil test correlation.

The influence of moisture among the warmer soils can be evaluated by comparing the Argiustolls (dry, warm) to the Haplustolls (moist, warm). Although only the Bray 1:7 showed a significant difference between groups, for all tests, the drier group had the highest r value. Also, all soil tests had significant correlations for the Argiustoll group, but none of the tests had significant correlations for the Haplustoll group.

In summary, temperature seemed to exert the greatest influence on the correlation between soil test and yield increase, the warmer Ustolls being more predictable than the cooler Borolls. Specifically, the difference lies between the aridic or typic Ustolls (dry, warm) and the aridic or typic Borolls (dry, cool). In addition, there appears to be a trend among the Ustolls showing greater predictability for the Argi (dry) than for the Haplo (moist) great groups.

The significant influence of climate, as categorized by the comprehensive system, on the correlation between soil tests and yield increase prompted further study of the influence of genetic factors on the soil tests investigated. A multiple regression analysis employing dummy variables was conducted to investigate the influence various genetic factors have on the relationship between soil tests and yield response to P fertilization.

The regression program used selected the most significant independent variable first. The next step selected the variable explaining the greatest amount of variance unexplained by the variables or variable already in the equation. This process continued until the F ratio for the next variable to be entered dropped below .01 or the tolerance dropped below .001. The tolerance for an independent variable was calculated as the proportion of the variance of that variable not explained by the independent variables already in the regression equation.

Stepwise elimination of variables was then conducted by hand and all variables were deleted which did not, upon elimination, result in a significant decrease in regression sum of squares. The first group of significant variables encountered and all following variables were included in the resulting regression equation as advised by Dr. Lee Tucker, Experiment Station Statistician. Significance was determined by the F ratio which was computed as the change in sum of squares for the step in question, with one degree of freedom, divided by the final error mean square.

The results of this analysis for the Modified Bray 1:50 soil test are reported in Table 9. The list from which the variables were selected is recorded in Table 8. All but three of the variables considered could be eliminated stepwise from the regression without a significant reduction in the regression sum of squares. The three significant variables were the Modified Bray 1:50, Ustoll, and vertic. These variables explained 51% of the yield response.

The Ustolls responded less to P fertilization than did the other soils as indicated by the negative partial regressions coefficient (Table 9). This may be due to basic differences in the P fractions of these soils. Westin and Buntley (62) found that Ustolls in South Dakota have slightly less organic P and lower organic C/organic P ratios than Borolls. The warmer temperatures, however, would cause more rapid mineralization which would in turn release more P for crop uptake. The lower C/P ratio of the organic matter in these soils would likely cause this factor to be even more significant. The additional P released from mineralization would cause these soils to respond less than the Borolls at the same soil test level. Westin and Buntley also reported that Ustolls have more iron and reductant P and less calcium P than Borolls. This may also be a factor in causing the difference in response of these soils.

The positive partial regression coefficient for the vertic variable indicates these soils respond more to P fertilization than do other soils at the same Modified Bray 1:50 level. The vertic soils are fine textured, clay soils and the Modified Bray 1:50 test was shown earlier to extract more P from these fine-textured soils. It may be extracting more P than is actually available for small grains, thus, these soils appear to respond more to P fertilization than other soils do at the same soil test level. Since the Modified Bray 1:7 test was not correlated with texture, the vertic subgroup was not

Table 8. Independent variables included in the multiple regression analysis of 74 small grain experiments.

Independent Variable	Description
BRF	Modified Bray 1:50, pp2m P
Bor	Suborder Boroll (0,1)
UST	Suborder Ustoll (0,1)
Arg	Great group Argi (0,1)
Hap	Great group Haplo (0,1)
PM1	Parent material Eolian sand (0,1)
PM2	Parent material Loess (0,1)
PM3	Parent material Residual (0,1)
PM4	Parent material Alluvium (0,1)
SG1	Subgroup Typic (0,1)
SG2	Subgroup Aridic (0,1)
SG3	Subgroup Udic or Hapludic (0,1)
SG4	Subgroup Pachic udic (0,1)
SG5	Subgroup Aquic (0,1)
SG6	Subgroup Vertic (0,1)
Sor	P Sorption Index
M1	Crop oats (0,1)
M2	Crop barley (0,1)
M3	Crop winter wheat (0,1)
PH1	$\mathrm{pH} < 6.6$ (0,1)
PH2	$7.6 > \mathrm{pH} > 7.0$ (0,1)
PH3	$\mathrm{pH} > 7.5$ (0,1)
T1	Texture Sandy loam (0,1)
T2	Texture Clay loam or Silty clay loam (0,1)
T3	Texture Silty Clay or Clay (0,1)
OM	Percent Organic matter
Bor X	Bor * BRF
Ust X	Ust * BRF
Arg X	Arg * BRF

Table 8. Continued.

Independent Variable	Description
Hap X	Hap * BRF
PM1 X	PM1 * BRF
PM2 X	PM2 * BRF
PM3 X	PM3 * BRF
PM4 X	PM4 * BRF
SG1 X	SG1 * BRF
SG2 X	SG2 * BRF
SG3 X	SG3 * BRF
SG4 X	SG4 * BRF
SG5 X	SG5 * BRF
SG6 X	SG6 * BRF
M1 X	M1 * BRF
M2 X	M2 * BRF
M3 X	M3 * BRF
P1 X	PH1 * BRF
P2 X	PH2 * BRF
P3 X	PH3 * BRF
T1 X	T1 * BRF
T2 X	T2 * BRF
T3 X	T3 * BRF
P1 T	PH1 * T1
P2 T	PH2 * T1
P3 T	PH3 * T1
P4 T	PH1 * T2
P5 T	PH2 * T2
P6 T	PH3 * T2
P7 T	PH1 * T3
P8 T	PH2 * T3
P9 T	PH3 * T3
P1 S	PH1 * Sor
P2 S	PH2 * Sor
P3 S	PH3 * Sor

Table 8. Continued.

Independent Variable	Description
R1 X	OM * BRF
RD 1	OM * Bor
RD Z	OM * Ust
RE 1	OM * Arg
RE Z	OM * Hap
RF 1	OM * SG1
RF 2	OM * SG2
RF 3	OM * SG3
RF 4	OM * SG4
RF 5	OM * SG5
RF 6	OM * SG6
RG 1	OM * PM1
RG 2	OM * PM2
RG 3	OM * PM3
RG 4	OM * PM4
RM 1	OM * M1
RH 2	OM * M2
RM 3	OM * M3
RP 1	OM * PH1
RP 2	OM * PH2
RP 3	OM * PH3
RT 1	OM * T1
RT 2	OM * T2
RT 3	OM * T3

Bor X through RT 3 are interaction variables where * indicates multiplication.

Table 9. Stepwise multiple regression for estimating Y, the log of the percent yield increase from P fertilization over the check yield, using genetic factors and Modified Bray 1:50.*

INDEPENDENT VARIABLES, X	R	R^2	F-SIGN	
BRF,UST,SG6	.716	.513	6.57	.025
BRF,UST	.682	.465	5.58	.025
BRF	.639	.409		

THE FINAL EQUATION: $Y=1.8791-.0078X_1-.2139X_2+.3623X_3$

INDEPENDENT VARIABLE	DESCRIPTION
X_1=BRF	MODIFIED BRAY 1:50,PP2M
X_2=UST	SUBORDER USTOLL (0,1)
X_3=SG6	SUBGROUP VERTIC (0,1)

*The genetic factors included in the regression analysis are "Bor" through "SG6" and "BORX" through "SG6X" in Table 8.

significant in regression analysis with this test.

Table 10 contains the result of the multiple regression analysis using the Modified Bray 1:7 soil test. All but two variables considered could be eliminated stepwise from the regression without a significant reduction in the regression sum of squares. The two variables were Modified Bray 1:7 and Ustoll * Bray 1:7. Here, as in the 1:50 test, the Ustolls responded less than the other soils, however, the manner in which they responded less differed. In this

Table 10. Stepwise multiple regression for estimating Y, the log of the percent yield increase from P fertilization over the check yield, using genetic factors and Modified Bray 1:7.*

INDEPENDENT VARIABLES, X	R	R^2	F-SIGN	
USTX,BRS	.654	.428	3.17	.10
USTX	.632	.399		

THE FINAL EQUATION: $Y=1.5768-.0098X_1-.0063X_2$

INDEPENDENT VARIABLE	DESCRIPTION
X_1=USTX	(UST(0,1))*(BRS)
X_2=BRS	MODIFIED BRAY 1:7,PP2M

*The genetic factors included in the regression analysis are "Bor" through "SG6" and "BORX" through "SG6X" in Table 8. All BRF variables were replaced with BRS.

case the difference in response due to a soil being a Ustoll was not constant but varied with soil P test level, the largest difference occurring with the highest soil tests. This is evident from the Ustoll * Bray 1:7 interaction term.

Influence of pH

The second factor studied was pH. The influence of pH on mean extractable P by the various soil tests is presented in Figure 8. Generally all five soil tests extracted less P as the pH increased. A similar effect on Connecticut soils using the Bray 1:10 was found by Griffin (17).

The exception to this trend of decreasing extractable P with

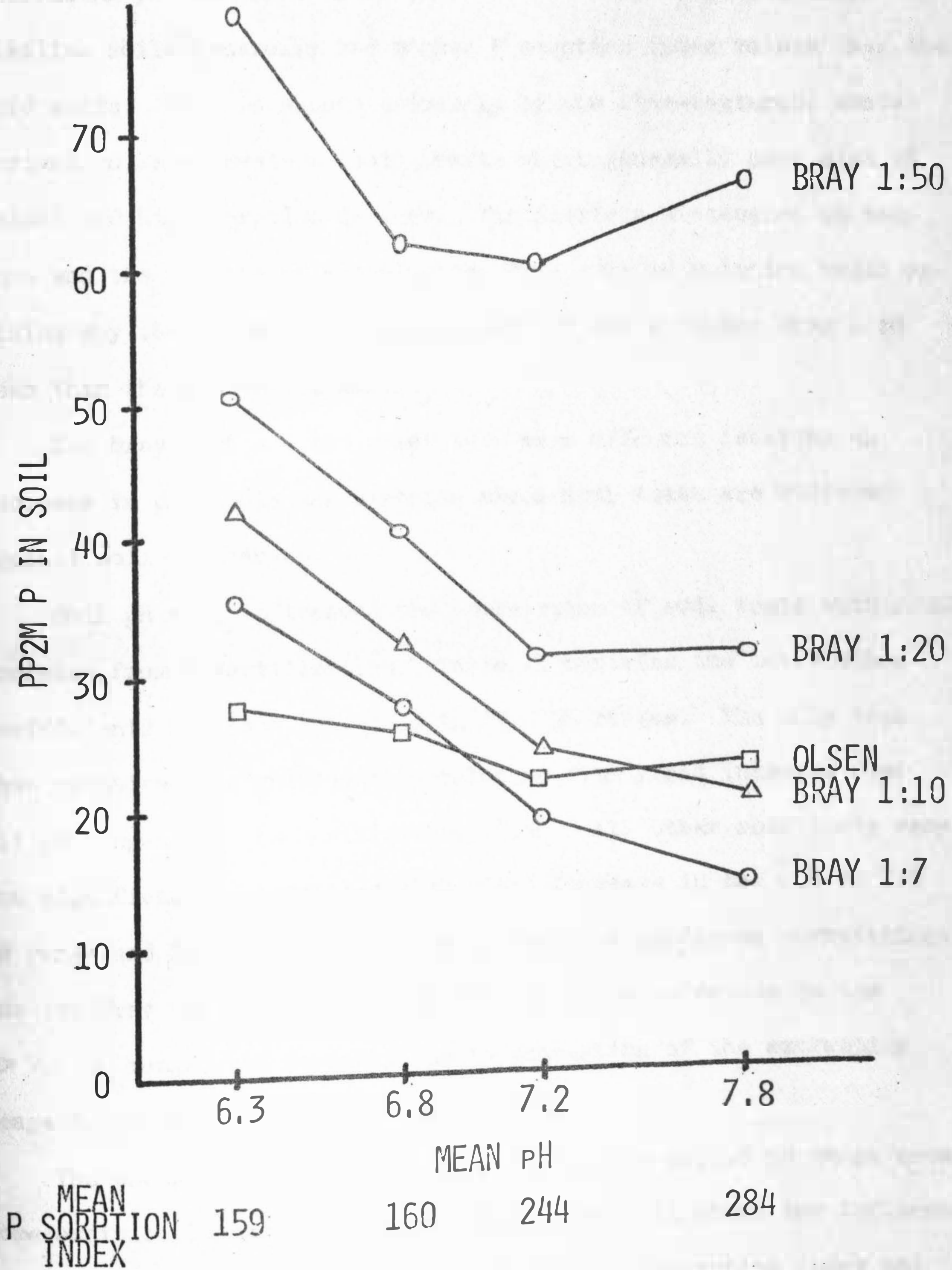

FIGURE 8. THE EFFECT OF pH ON $\bar{X}$ EXTRACTABLE P.

increasing pH was the Bray 1:50 test at pH 7.8. Figure 8 shows the alkaline soils generally had higher P sorption index values than the acid soils. This is caused primarily by the fine-textured, shale-derived soils of western South Dakota which generally have high pH values and high sorption indices. The previous discussion on texture and the effects of widening the Bray soil to solution ratio explains why the soils with a mean pH of 7.8 had a higher Bray 1:50 mean than the 6.8 or 7.2 soils.

The Bray 1:50 and the Olsen test were affected least by an increase in pH. This was expected since both tests are buffered against soil pH changes.

Soil pH also influenced the correlation of soil tests with yield increase from P fertilization. Table 11 contains the correlation coefficients for each soil test in five pH ranges. The only test that exhibited a significant correlation with yield increase over all pH ranges was the Modified Bray 1:50. All other soil tests were not significantly correlated with yield increase in the 6.6 to 7.0 pH range and in the >7.5 pH range. The nonsignificant correlations for the Bray tests with narrower soil to solution ratios in the >7.5 pH range, are probably due to exhaustion of the extracting reagent by $CaCO_3$ as was discussed earlier.

The unexpected poor correlation in the 6.6 to 7.0 pH range caused some additional comparisons to be made. Table 12 shows the influence of pH and suborder on the correlation between P sorption index and texture or organic matter. In each case where low correlations

Table 11. The effect of pH on simple correlation coefficients between the log of the percent yield increase over the check and each soil test.

	pH				
Soil Test	<6.6	6.6-7.0	7.1-7.5	>7.5	>7.1
Modified Bray 1:7	-.818**	-.333	-.475*	-.387	-.446*
1:10	-.768**	-.166	-.509*	-.621	-.590**
1:20	-.785**	-.360	-.464*	-.633	-.614**
1:50	-.850**	-.366*	-.542*	-.743*	-.660**
Olsen P	-.741**	-.214	-.546*	-.561	-.605**
Sorption Index	+.141	+.038	-.590**	-.621	-.697**
Number	15	30	20	9	20

* Significant at .05 level

** Significant at .01 level

Table 12. Simple correlation coefficients between the sorption index and texture or oganic matter.

	pH						
	<6.6	6.6-7.0	7.1-7.5	>7.5	>7.1	Borolls	Ustolls
Sorption Index & Texture	+.477	+.293	+.364	+.720*	-.620**	+.166	+.838**
Sorption Index & O.M.	+.652**	+.210	+.065	+.185	+.009	+.512**	+.105

* Significant at .05 level

** Significant at .01 level

between soil test and yield increase prevailed, a low correlation between sorption index and texture was found.

In the case of Borolls, which were shown earlier to have low correlations between soil tests and yield increase, P sorption was correlated with organic matter. With soils in the pH range of 6.6 to

7.0, however, sorption index was correlated with neither texture or organic matter. Both Olsen and Bray soil tests have been shown to be highly correlated with the aluminum phosphate fraction (61,42,52,28) according to the procedure of Chang and Jackson (8). Murrman and Peech (31) stated that this fraction must include adsorbed P. The unexplained source of P sorption in this group of soils may, then be associated with the low correlation between the soil tests and yield increase from P fertilization. The exact nature of this association cannot be explained by information from this study. Additional research is needed to determine if this relationship is significant and, if so, what the nature of that relationship is.

Table 11 shows that for soils having a pH greater than 7.1, the sorption index had the highest correlation with yield increase of all the soil tests. In this pH range, the sorption index and Modified Bray 1:50 P had a highly significant correlation coefficient of .590. This indicates that the soils of greater P sorption ability also had more available P occupying the sorption sites. Thus, the greater the sorption index, the smaller the yield increase.

For acid soils (pH < 7.0), sorption index and yield increase were not correlated showing an r value of -.022. In this pH range, sorption index and Modified Bray 1:50 had an r value of .054 which was not significant. Apparently, sorption sites in the alkaline soils tended to be occupied by available P where as for the acid soils they were not. This explains why the sorption index was correlated with yield increase for the alkaline soils but not for the acid soils.

Combined Influence of Several Factors

The combined influence of P soil tests, genetic factors, pH, organic matter, crop species, and texture, together with selected first order interactions, were evaluated using stepwise multiple regression analysis employing dummy variables. The procedure followed was the same as that used earlier where only soil test and genetic factors were considered.

The results of the analysis with the Modified Bray 1:7 and sorption index are reported in Table 13. The resulting equation contained 9 variables which explained 60.5% of the variation in yield response. The most significant variable, X_1, was the same as in Table 10, the Ustoll * Bray 1:7 interaction term. The next most significant variable, X_2, was an interaction term between winter wheat and Bray 1:7. The negative partial regression coefficient indicates that winter wheat responds less to P fertilization than other crops at the same Bray 1:7 level. This may be due to the extra input of P that winter wheat has from mineralization of organic matter during the fall. This would not be accounted for by the Bray 1:7 test.

The P2S term indicates that on alkaline soils, response to P application decreased as the sorption index increased. This is in agreement with the data in Table 12 which showed a negative simple correlation coefficient between yield increase and sorption index.

Variable X_4 showed that residual soils responded less to P fertilization than other parent materials, the higher the Bray 1:7

Table 13. Stepwise multiple regression for estimating Y, the log of the percent yield increase from P fertilization over the check yield, using the Modified Bray 1:7 and the sorption index.*

INDEPENDENT VARIABLES, X	R	R^2	F-SIGN	
USTX,M3X,P2S,PM3X,P8T,RG4,P4T,T2X,RP2	.778	.605	7.57	.025
USTX,M3X,P2S,PM3X,P8T,RG4,P4T,T2X	.761	.578	8.38	.025
USTX,M3X,P2S,PM3X,P8T,RG4,P4T	.741	.549	4.56	.10
USTX,M3X,P2S,PM3X,P8T,RG4	.730	.533	10.21	.025
USTX,M3X,P2S,PM3X,P8T	.705	.497	4.67	.10
USTX,M3X,P2S,PM3X	.694	.481	5.61	.05
USTX,M3X,P2S	.679	.462	5.37	.05
USTX,M3X	.665	.443	12.41	.01
USTX	.632	.399		

THE FINAL EQUATION:

$$Y=1.5294-.0108X_1-.0039X_2-.0017X_3-.0052X_4+.8833X_5-.1687X_6+.4878X_7-.0074X_8+.0905X_9$$

INDEPENDENT VARIABLE	DESCRIPTION
X_1=USTX	(UST (0,1))*(BRS)
X_2=M3X	(WINTER WHEAT (0,1))*(BRS)
X_3=P2S	(7.6>pH>7.0(0,1))*(SORPTION INDEX)
X_4=PM3X	(RESIDUAL (0,1))*(BRS)
X_5=P8T	(7.6>pH>7.0(0,1))*(SiC or C (0,1))
X_6=RG4	(ALLUVIUM (0,1))*OM
X_7=P4T	(pH<6.6(0,1))*(Cl or SiCl (0,1))
X_8=T2X	(Cl or SiCl (0,1))*BRS
X_9=RP2	(7.6>pH>7.0 (0,1))*OM

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*The variables included in the regression analysis are those listed in table 8, except that BRF in all cases was substituted with BRS.

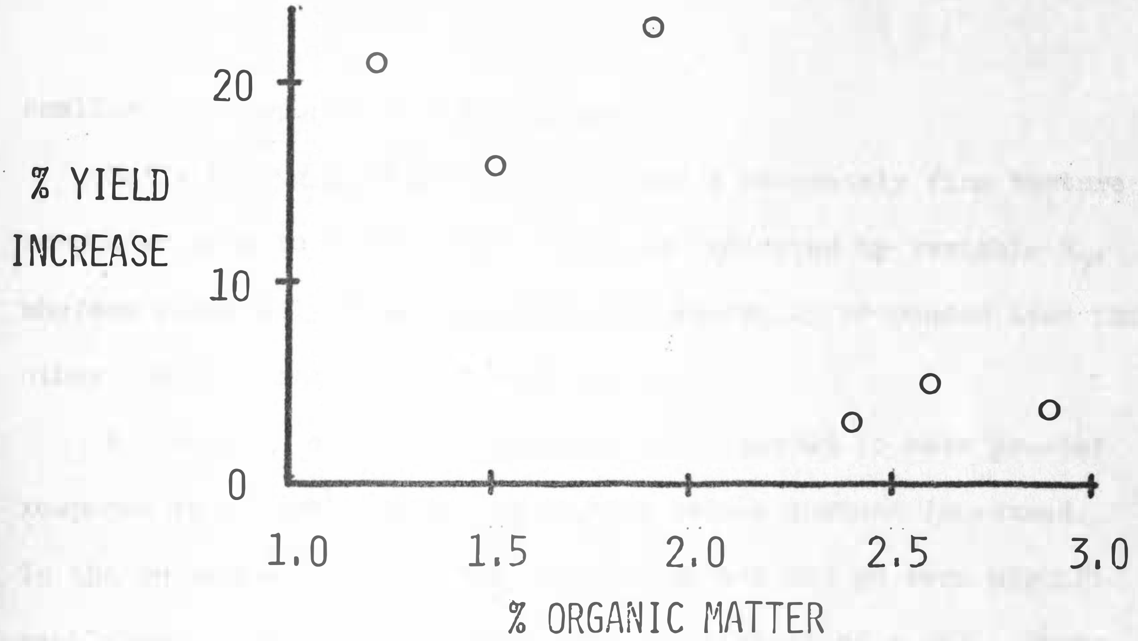

FIGURE 9. THE INFLUENCE OF ORGANIC MATTER ON YIELD INCREASE FROM P FERTILIZATION ON ALLUVIAL SOILS.

extractable P, the greater the difference.

Fine-textured alkaline soils responded substantially more than other soils as indicated by variable X_5. For alkaline soils, the simple correlation coefficient between Bray 1:7 P and texture was +.734 which was significant at the .01 level. For acid soils, however, Bray 1:7 P was not correlated with texture as was pointed out earlier in this study. This appears to indicate that the Bray 1:7 test is overestimating the available P-supplying ability of these fine-textured alkaline soils.

Variable X_6 shows that as organic matter increased in alluvial soils, yield increase from P fertilization decreased. Figure 9 depicts graphically this relationship for the six experiments on alluvial soils. Evidently, the greater the organic matter content of these soils, the greater the P released upon mineralization and the smaller the response to P fertilizer.

Soils having a pH less than 6.6 and a moderately fine texture responded more to P than other soils as indicated by variable X_7, whereas moderately fine-textured soils generally responded less than other soils as indicated by variable X_8.

Variable X_9 shows that alkaline soils tended to have greater response to P fertilization as organic matter content increased. In the pH range of 7.1 to 7.5, organic matter and pH were significantly correlated with a correlation coefficient of +.462. Therefore, it is suggested that the impact of variable X_9 is due primarily to pH and organic matter content is significant due to its correlation with pH.

Since the P sorption index as determined in this study is not currently conducted on soils in routine soil testing procedures, a regression analysis was conducted using the Modified Bray 1:7 without the P sorption index. The results of this analysis are reported in Table 14. The resulting equation contained eleven variables which explained 61.4% of the variation in yield response. This is approximately the same amount explained with the sorption index included but two additional variables were required to do it. The two equations are similar. The equation without the sorption index included, contains six variables not included in the previous equation, but four of those six contain either texture or organic matter terms which, in turn, are related to sorption index.

Variable X_3 was the first new variable encountered in this

Table 14. Stepwise multiple regressing for estimating Y, the log of the percent yield increase from P fertilization over the check yield, using the Modified Bray 1:7 without the sorption index.*

INDEPENDENT VARIABLES, X	R	R^2	F-SIGN.	
USTX,M3X,PM1,RG4,SG2,T2,P4T,RF2,RT2,P8T,P2X	.784	.614		
			4.77	.05
USTX,M3X,PM1,RF4,SG2,T2,P4T,RF2,RT2,P8T	.773	.597		
			4.50	.10
USTX,M3X,PM1,RF4,SG2,T2,P4T,RF2,RT2	.762	.581		
			8.18	.025
USTX,M3X,PM1,RG4,SG2,T2,P4T,RF2	.743	.552		
			4.01	.10
USTX,M3X,PM1,RF4,SG2,T2,P4T	.734	.538		
			7.97	.025
USTX,M3X,PM1,RG4,SG2,T2	.714	.510		
			5.24	.05
USTX,M3X,PM1,RG4,SG2	.701	.492		
			5.86	.05
USTX,M3X,PM1,RG4	.686	.471		
			3.52	.10
USTX,M3X,PM1	.677	.459		
			4.57	.10
USTX,M3X	.665	.443		
			18.07	.005
USTX	.632	.399		

Table 14. Continued.

THE FINAL EQUATION: $Y=1.5051-.0111X_1-.0093X_2+1031X_3-.2006X_4+1.8076X_5$
$-.8392X_6+.6112X_7-.6713X_8+.2087X_9+.5707X_{10}-.0063X_{11}$

INDEPENDENT VARIABLE	DESCRIPTION
X_1 = USTX	(UST (0.1))* (BRS)
X_2 = M3X	(Winter wheat (0,1))* (BRS)
X_3 = PM1	Eolian sand (0,1)
X_4 = RG4	(Alluvium (0,1))* (OM)
X_5 = SG2	(Aridic (0,1)
X_6 = T2	Cl or SiCl (0,1)
X_7 = P4T	(pH $<$ 6.6 (0,1))* (Cl or SiCl (0,1))
X_8 = RF2	(Aridic (0,1))* (OM)
X_9 = RT2	(OM)* (Cl or SiCl (0,1))
X_{10}= P8T	(7.6 $>$ pH $>$ 7.0 (0,1))* (SiC or C (0,1))
X_{11}= P2X	(7.6 $>$ pH $>$ 7.0 (0,1))* (BRS)

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* The variables included in the regression analysis are those listed in Table 8, except that Sor was excluded and BRF in all cases was substituted with BRS.

equation. The coarse texture and low P sorption ability of these soils formed from eolian sand, probably caused the P reserve of these soils to be quite low, thus, the capacity factor as discussed by Williams (23), was quite low.

Variable X_5 indicates that soils of the aridic subgroup responded more to P fertilization than other soils after variables X_1 through X_4 were controlled.

Variable X_8 shows that as organic matter increased in soils with aridic subgroups, response to P fertilization decreased. All five of these soils, however, were developed from alluvium and were included in variable X_4. It is difficult, then, to determine if it is the alluvial parent material, the aridic subgroup, or a combination of both that cause these soils to act as they do. Since X_4 was selected first and was therefore, most significant at an earlier step in the analysis, it follows that the parent material may likely have been the most important criteria.

Variable X_9 shows that for moderately fine-textured soils, yield response increased as organic matter content increased provided the first eight variables were controlled. There is a number of potential explanations for this relationship but with the limited information available here, it becomes difficult to determine which is correct. The fertilizer P may be initially adsorbed by the organic matter, preventing its fixation by other soil components. This P may then be released to the crop as it is needed, thereby, reducing the fertilizer P fixed in unavailable forms. This type of reaction was reported by Harter (24) for some Connecticut soils.

Table 15. Stepwise multiple regression for estimating Y, the log of the percent yield increase from P fertilization over the check yield, using the Modified Bray 1:50 and the sorption index.*

INDEPENDENT VARIABLES, X	R	R^2	F-SIGN.	
BRF,UST,T3X,P2S,M2X,RM2,RD1	.801	.642	6.68	.025
BRF,UST,T3X,P2S,M2X,RM2	.786	.617	10.23	.01
BRF,UST,T3X,P2S,M2X	.762	.581	7.30	.025
BRF,UST,T3X,P2S	.745	.554	10.03	.01
BRF,UST,T3X	.720	.518	14.88	.005
BRF,UST	.682	.465	15.64	.005
BRF	.639	.409		

THE FINAL EQUATION: $Y=1.8501-.0098X_1-.0804X_2+.0050X_3-.0008X_4+.0117X_5-.1924X_6+.0736X_7$

INDEPENDENT VARIABLE	DESCRIPTION
X_1=BRF	MODIFIED BRAY 1:50,PP2M
X_2=UST	SUBORDER USTOLL (0,1)
X_3=T3X	(SIC OR C (0,1))*(BRF)
X_4=P2S	(7.6>PH>7.0(0,1))*(SORPTION INDEX)
X_5=M2X	(BARLEY (0,1))*(BRF)
X_6=RM2	(BARLEY (0,1))*OM
X_7=RD1	(BOROLL (0,1))*OM

*The variables included in the regression analysis are those listed in Table 8.

As would be expected for alkaline soils, as the Bray 1:7 P increased, yield response decreased. This is indicated by variable X_{11}.

The two equations involving the Modified Bray 1:7 test did not include the Bray 1:7 test as a main effect but only as first order interaction terms. The Modified Bray 1:50, however, was a significant variable in both equations developed with this test and the first variable entered in both cases. Table 15 contains the results of the regression analysis using the Modified Bray 1:50 test with the sorption index. The resulting equation contained seven variables which explained 64.2% of the variation in yield response, 23% more than the Bray 1:50 test could explain alone.

As indicated by variable X_2, the Ustolls responded less to P fertilization at the same Bray 1:50 level than did other soils, primarily the Borolls. This agrees with the conclusions drawn from Table 10 where only genetic factors were considered.

The next variable entered, X_3, was an interaction term between fine-textured soils and the Bray 1:50 test. In Table 9 the third variable entered was vertic. Thus, a texture term replaced the vertic subgroup which indicates the extremely fine texture of these soils was the factor causing them to differ from the other soils in their response to P fertilizer. The cause of this difference was discussed earlier.

With the Bray 1:50 test, the only term containing the sorption index was variable X_4, which represents an interaction term between the alkaline soils and the sorption index. As the sorption index increased in these soils, response to P fertilization decreased. The explanation for this relationship was discussed in the section on the influence of pH on soil test correlation.

Variables X_5 and X_6 both contain barley as part of the interaction terms and will be discussed together. Variable X_5 shows that barley responded more to P fertilization than did other crops at the same soil test level and that the difference in response increased as Bray P increased. This tendency of barley to be an inefficient feeder of native soil P has been noted by several investigators (30, 65). Variable X_6 shows that as soil organic matter content increased, the response of barley to P fertilization decreased. Weaver (59) showed that the roots of barley tend to be more concentrated near the surface than do roots of other small grains. This may allow them to utilize more of the P associated with organic matter which also tends to be concentrated near the soil surface.

The final significant variable included in the equation, X_7, indicated that as organic matter increased in Borolls, response to P fertilization also increased. The cooler soil temperatures of Borolls likely result in lower mineralization rates which in turn would tend to minimize the influence of organic matter on the available P-supplying ability of these soils. Westin (62) reported that Borolls have higher organic C/organic P ratios in South Dakota than do Ustolls. This may also be a factor minimizing the contribution of organic P. These factors explain why a negative correlation did not exist between organic matter and yield response but do not explain the positive correlation. The positive correlation between organic matter and yield response may be due to the adsorbing of P by the organic matter as Harter's research showed which was referred to earlier.

Table 16 contains the results of regression analysis using the Modified Bray 1:50 without the sorption index. The resulting equation contained seven variables and explained 61.7% of the variation in yield response. This equation was very similar to the equation with the sorption index, differing only in one variable. In this equation, P2S was replaced with PH2.

A comparison of the predicted yield increases from the four equations developed with observed yield increases can be found in Table 17.

Table 16. Stepwise multiple regression for estimating Y, the log of the percent yield increase from P fertilization over the check yield, using the Modified Bray 1:50 without the sorption index.*

INDEPENDENT VARIABLES, X	R	R^2	F-SIGN.	
BRF,UST,T3X,M2X,RM2,PH2,RD1	.786	.617	5.14	.05
BRF,UST,T3X,M2X,RM2,PH2	.772	.596	5.54	.05
BRF,UST,T3X,M2X,RM2	.757	.573	8.22	.025
BRF,UST,T3X,M2X	.734	.539	4.92	.05
BRF,UST,T3X	.720	.518	12.92	.005
BRF,UST	.682	.465	13.58	.005
BRF	.639	.409		

THE FINAL EQUATION: $Y = 1.8671-.0099X_1-.0903X_2+$
$.0045X_3+.0119X_4-.2000X_5-.1740X_6+.0709X_7$

INDEPENDENT VARIABLE	DESCRIPTION
X_1 = BRF	Modified Bray 1:50,pp2m
X_2 = UST	Suborder Ustoll (0,1)
X_3 = T3X	(SiC or C (0,1))* (BRF)
X_4 = M2X	(Barley (0,1))* (BRF)
X_5 = RM2	(Barley (0,1))* OM
X_6 = PH2	7.6 > pH > 7.0 (0,1)
X_7 = RD1	(Boroll (0,1))* OM

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* The variables included in the regression analysis are those listed in Table 8 except that Sor was excluded.

Table 17. Comparison of predicted yield increases from four multiple regression equations with observed yields

		Predicted Yield Increases (%)			
Sample Number	Observed % Yield Increase	1:7 and Sor	1:7 alone	1:50 and Sor	1:50 alone
1898	20	16	10	32	33
1902	17	22	32	19	20
1908	31	24	32	25	26
1917	32	34	57	16	16
1921	50	25	32	23	24
1931	8	17	15	15	16
1937	50	34	32	27	28
1943	38	34	32	19	20
1948	71	34	41	46	47
1958	25	34	41	32	32
1963	50	19	33	28	28
1980	45	34	32	28	27
2611	16	20	18	19	19
2623	50	34	32	30	30
2658	8	8	8	11	11
2668	17	19	17	17	17
2678	29	20	18	20	20
2690	19	17	19	16	16
2716	51	53	34	48	32
2723	42	34	32	36	36
3150	48	30	21	37	37
3155	14	19	18	25	24
3159	16	34	32	38	37
3164	23	19	17	22	22
3217	46	20	19	24	24
3222	11	11	10	8	8
3226	16	19	16	22	23
3237	39	25	25	33	38
3494	10	8	12	10	8
3543	25	27	18	17	14
3614	21	34	32	25	23
3637	28	29	27	33	30
3674	66	34	32	36	35
4016	6	15	17	22	24
4070	63	34	32	35	33

Table 17. Continued

Sample Number	Observed % Yield Increase	Predicted Yield Increases (%)			
		1:7 and Sor	1:7 alone	1:50 and Sor	1:50 alone
4098	17	34	32	36	37
5002	48	29	25	29	29
5116	23	19	24	8	8
5121	11	17	16	15	15
5131	28	34	32	29	30
5136	6	13	12	8	8
5141a	7	14	14	8	8
5141c	25	14	14	19	19
5141b	8	14	14	8	8
5156	28	16	20	20	21
5173	34	49	25	46	38
5177	16	34	32	43	43
5735	4	5	4	6	9
5740	3	5	4	4	4
6002	0	1	1	1	1
6007	25	17	16	17	18
6364	21	8	20	17	17
6379	26	23	22	27	25
7282	24	16	15	17	13
7299	50	34	32	37	36
7320	22	34	32	35	35
1326	33	29	21	61	62
13410	5	13	13	13	13
13427	12	34	32	18	18
13435	5	4	4	6	6
13515	9	21	13	18	18
16973-86	39	30	26	27	27
17002-17	38	43	29	47	38
17042-57	43	17	20	15	15
17062-76	32	34	32	29	30
17116	21	22	28	26	27
19880a	12	15	17	13	13
19880b	10	15	17	13	13
19880c	28	15	17	30	29
20012	7	23	25	14	12
20038a	15	19	26	21	25
20038b	19	19	26	20	23
20038c	24	19	26	21	25
20038d	25	19	26	21	25

SUMMARY AND CONCLUSIONS

Field experiments involving phosphorus fertilization of small grains in South Dakota were used to accomplish two objectives. The first objective was to evaluate the effectiveness of several soil tests in predicting yield response to P fertilization. The second objective was to evaluate the influence other soil and environmental factors have on the relationship between soil test and yield response from P fertilization.

The correlation between soil test and yield response to P fertilization continually increased as the soil to solution ratio of the Bray 1 test widened. The Olsen test did not do a better job of explaining response than the Bray tests. The soil test most highly correlated with yield response for all 74 soils was the Modified Bray 1, 1:50 which explained 41% of the variation in yield response.

Generally, the Borolls were less predictable in their response to P than were the Ustolls. Also, the Ustolls responded less to P fertilization than other soils while soils of the vertic subgroup responded more to P fertilizer, according to the Modified Bray 1, 1:50 soil test, than did other soils.

An influence of pH on the soil tests was observed. For the Modified Bray 1:7, 1:10, and 1:20, as pH increased, extractable P decreased. Slightly acid soils (6.6-7.0) exhibited lower correlation with yield response than soils of other pH's while acid soils (< 6.6) exhibited the highest correlations. The P sorption index was highly correlated with response to P fertilization for alkaline soils but showed no correlation with yield response on the acid soils.

Multiple regression analysis was used to evaluate the combined influence of several factors on the correlation between soil test and yield response. The results revealed that texture, pH, organic matter, parent material, soil classification, and crop species all influenced this relationship. The equation developed with the Modified Bray 1, 1:7 contained eleven variables and explained 61% of the variation in yield response. The equation developed with the Modified Bray 1, 1:50 contained seven variables and explained 62% of the variation in yield response.

In this study, the Modified Bray 1, 1:50 was most related to yield response. When considering other factors, fewer variables were required to explain yield response than with other tests. For these reasons, it is concluded that this soil test is superior to the others evaluated in predicting yield response from P fertilization on South Dakota soils.

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Appendix A. R, R^2, and significance for each step in the multiple regression analysis with the Modified Bray 1:7 without the sorption index.

Variable	R	R^2	Sign.*
UstX	0.631	0.399	
M3X	0.665	0.442	.005
PM1	0.677	0.458	.100
RG4	0.686	0.471	.100
SG2	0.701	0.491	.050
T2	0.714	0.510	.050
P4T	0.733	0.538	.025
RF2	0.743	0.552	.100
RT2	0.762	0.581	.025
P82	0.772	0.597	.100
P2X	0.783	0.613	.050
P9T	0.791	0.626	.100
SG1X	0.799	0.638	.100
P1T	0.805	0.648	NS
SG6	0.810	0.656	NS
M3	0.814	0.662	NS
UST	0.818	0.669	NS
M2X	0.821	0.674	NS
BRS	0.825	0.681	NS
RM2	0.830	0.689	NS
M2	0.835	0.697	NS
HapX	0.837	0.700	NS
RM3	0.838	0.703	NS
PM3X	0.840	0.705	NS
RG1	0.841	0.708	NS
SG4X	0.843	0.711	NS
RF4	0.850	0.722	.100
P5T	0.853	0.728	NS
P2	0.863	0.744	.100
PM3	0.866	0.751	NS
SG6X	0.884	0.781	.025
PM4X	0.890	0.793	.100
RF6	0.896	0.804	NS
RP1	0.902	0.814	NS
P1X	0.905	0.819	NS
OM	0.909	0.827	NS
R1X	0.914	0.836	NS
Hap	0.918	0.843	NS
PM1X	0.924	0.855	.100
SG4	0.927	0.860	NS
T2X	0.932	0.869	NS
RO2	0.936	0.877	NS
RG3	0.945	0.893	.050
M1X	0.948	0.899	NS
P2T	0.950	0.902	NS
P6T	0.951	0.905	NS
ArgX	0.954	0.910	NS
SG1	0.957	0.916	NS
P1	0.958	0.918	NS
P3T	0.958	0.919	NS
RGZ	0.959	0.920	NS
PMZ	0.967	0.935	.100
SG3X	0.970	0.941	NS
RP3	0.973	0.947	NS
P3X	0.974	0.948	NS
RE1	0.974	0.949	NS
RP2	0.974	0.950	NS
M1	0.975	0.950	NS
PM2X	0.975	0.950	NS

*Indicates significance of that variable as indicated by F ratio for change in regression sum of squares upon elimination of the variable.

Appendix B. R, R^2, and significance for each step in the multiple regression analysis with the Modified Bray 1:7 and the sorption index.

Variable	R	R^2	Sign.*
USTX	0.631	0.399	[illegible]
M3X	0.665	0.442	.010
P2S	0.679	0.461	.050
PH3X	0.693	0.481	.050
P89	0.705	0.497	.100
RG4	0.730	0.533	.025
P4T	0.741	0.549	.100
T2X	0.760	0.578	.025
RPZ	0.777	0.604	.025
SG2	0.786	0.618	.100
SG2X	0.791	0.627	NS
P3S	0.797	0.635	NS
SG6X	0.806	0.650	.100
RT3	0.818	0.670	.050
RF1	0.822	0.676	NS
PH3	0.826	0.682	NS
P6T	0.829	0.688	NS
M2X	0.832	0.692	NS
P5T	0.835	0.698	NS
RT2	0.845	0.714	.100
T2	0.851	0.724	NS
PM3	0.855	0.731	NS
RF6	0.875	0.765	.025
RM3	0.879	0.773	NS
M3	0.882	0.778	NS
P3X	0.889	0.791	.100
RG2	0.892	0.796	NS
PM2X	0.896	0.802	NS
SG4X	0.899	0.808	NS
RM2	0.904	0.818	NS
RF4	0.908	0.825	NS
RE1	0.912	0.831	NS
M1X	0.914	0.836	NS
BRS	0.916	0.840	NS
RD1	0.920	0.847	NS
SG3	0.929	0.863	.100
PM2	0.935	0.874	NS
PM1X	0.937	0.878	NS
P1T	0.939	0.883	NS
RP3	0.941	0.886	NS
PM4X	0.943	0.890	NS
ArgX	0.945	0.893	NS
R1X	0.947	0.898	NS
OM	0.950	0.903	NS
RG1	0.955	0.912	NS
P2X	0.959	0.919	NS
RG3	0.963	0.929	NS
Arg	0.968	0.938	NS
P9T	0.970	0.942	NS
SG1	0.973	0.947	NS
Sor	0.974	0.950	NS
M2	0.976	0.953	NS
RE2	0.978	0.958	NS
SG3X	0.979	0.958	NS
M1	0.979	0.959	NS
RT1	0.979	0.959	NS
PM1	0.979	0.960	NS
PH2	0.980	0.961	NS
RP1	0.980	0.961	NS
P1X	0.981	0.963	NS
RM1	0.981	0.963	NS
P1S	0.981	0.964	NS
PH1	0.983	0.967	NS
UST	0.984	0.968	NS

*Indicates significance of that variable as indicated by F ratio for change in regression sum of squares upon elimination of the variable.

Appendix C. R, R^2, and significance for each step in the multiple regression analysis with the Modified Bray 1:50 without the sorption index.

Variable	R	R^2	Sign.*
BRF	0.639	0.408	
UST	0.681	0.464	.005
T3X	0.720	0.518	.005
M2X	0.734	0.538	.050
RM2	0.756	0.572	.025
PH2	0.771	0.595	.050
RD1	0.785	0.617	.050
T2	0.793	0.629	NS
P4T	0.799	0.639	NS
HAPX	0.804	0.647	NS
RF1	0.813	0.662	.100
RG4	0.828	0.686	.050
PM4X	0.844	0.713	.050
RT2	0.848	0.719	NS
PM4	0.854	0.730	NS
RG3	0.859	0.738	NS
RF2	0.863	0.745	NS
PM3X	0.868	0.755	NS
RF6	0.876	0.767	NS
P2T	0.879	0.773	NS
R1X	0.882	0.779	NS
M3X	0.888	0.789	NS
PH3	0.892	0.797	NS
RD2	0.895	0.801	NS
M2	0.898	0.807	NS
P6T	0.901	0.813	NS
P5T	0.904	0.818	NS
BORX	0.908	0.824	NS
SG5X	0.911	0.831	NS
RT3	0.915	0.838	NS
P8T	0.918	0.842	NS
SG6	0.920	0.847	NS
OM	0.922	0.851	NS
PM3	0.927	0.859	NS
SG5	0.932	0.868	NS
P3X	0.933	0.872	NS
RP3	0.934	0.873	NS
RM1	0.935	0.875	NS
M1	0.936	0.876	NS
RP1	0.937	0.879	NS
RG2	0.938	0.881	NS
PM2X	0.940	0.885	NS
T2X	0.943	0.890	NS
SG1	0.944	0.891	NS
ARG	0.945	0.893	NS
M3	0.945	0.894	NS
RM3	0.946	0.895	NS
SG1X	0.947	0.898	NS
RE2	0.950	0.903	NS
P1X	0.951	0.905	NS
HAP	0.953	0.908	NS
PM2	0.955	0.912	NS
RF4	0.958	0.918	NS
SG4X	0.964	0.929	NS
SG3X	0.965	0.933	NS
P2X	0.968	0.938	NS
M1X	0.971	0.943	NS
P1T	0.973	0.947	NS
PM1	0.976	0.953	NS
SG4	0.976	0.954	NS
PH1	0.976	0.954	NS
RP2	0.976	0.954	NS

*Indicates significance of that variable as indicated by F ratio for change in regression sum of squares upon elimination of the variable.

Appendix D. R, R^2, and significance for each step in the multiple regression analysis with the Modified Bray 1:50 and the sorption index.

Variable	R	R^2	Sign.*
BRF	0.639	0.408	
UST	0.681	0.464	.005
T3X	0.720	0.518	.005
P2S	0.744	0.554	.010
M2X	0.762	0.580	.025
RM2	0.785	0.617	.010
RD1	0.800	0.641	.025
T2	0.809	0.655	.100
P2X	0.819	0.670	.100
P4T	0.828	0.686	.100
USTX	0.833	0.694	NS
RF1	0.837	0.701	NS
HAPX	0.845	0.715	.100
RG4	0.852	0.726	.100
PM4X	0.857	0.734	NS
RT2	0.859	0.738	NS
PM4	0.862	0.743	NS
RF2	0.866	0.750	NS
P5T	0.870	0.757	NS
RG3	0.873	0.762	NS
PM3X	0.884	0.783	.050
PM3	0.891	0.795	.100
SG3	0.895	0.801	NS
RF3	0.900	0.811	NS
SG1X	0.905	0.819	NS
M2	0.911	0.831	.100
SG3X	0.917	0.841	NS
RM3	0.920	0.847	NS
P3T	0.924	0.854	NS
RD2	0.927	0.859	NS
P8T	0.929	0.863	NS
R1X	0.931	0.866	NS
SG6	0.933	0.871	NS
RP3	0.935	0.875	NS
PH3	0.940	0.883	NS
PH2	0.943	0.889	NS
SOR	0.944	0.892	NS
OM	0.945	0.894	NS
RP1	0.946	0.895	NS
P1T	0.947	0.897	NS
RP2	0.949	0.900	NS
PM1	0.950	0.903	NS
SG1	0.951	0.905	NS
PH1	0.952	0.907	NS
P1S	0.953	0.909	NS
RF5	0.954	0.911	NS
P6T	0.955	0.913	NS
P1X	0.957	0.916	NS
M3	0.959	0.920	NS
T2X	0.961	0.925	NS
M3X	0.963	0.929	NS
PM2X	0.964	0.930	NS
RG2	0.971	0.942	.100
PM2	0.974	0.949	NS
P9T	0.976	0.953	NS
RE1	0.977	0.954	NS
RM1	0.977	0.955	NS
M1X	0.977	0.955	NS
RF4	0.977	0.955	NS
HAP	0.977	0.956	NS
SG5X	0.978	0.956	NS

*Indicates significance of that variable as indicated by F ratio for change in regression sum of squares upon elimination of the variable.