SOIL PHOSPHORUS TEST VALUES
AND WHEAT PRODUCTION

By

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CHAPTER I

INTRODUCTION

Along with certain other yield factors the available plant nutrient economy must be adequate for satisfactory plant growth and crop yield. For most deficient soils the essential elements will be supplied by fertilization and manuring. Even soils with adequate available plant nutrients may become deficient, after certain cropping cycles, in one or more of the elements. Among the three most important plant nutrients; nitrogen, phosphorus and potassium, that must be applied to the soil, the availability of phosphorus gives the most complicated nutritional problems both on acid and alkaline soils.

Many soil phosphorus test methods have been developed to predict the extent of phosphorus availability and the need of fertilizer to be added to the soil for a successful crop harvest. But soil test data would be of less value if there is no significant relation between the data and crop response.

The main objectives of this study were (1) to study the effects of continuous wheat cropping along with long-term fertilization treatments on plant nutrient availability, and (2) to investigate the relation between the chemical soil test and long-term average crop yield.

CHAPTER II

REVIEW OF LITERATURE

The Magnitude of Available Phosphorus Extracted by Different Methods: — Most of the extractants used for available phosphorus are mineral acids. The quantity of phosphorus extracted is generally assumed to be proportional to the strength of the acid. However, many investigators have reported different results on different soils or even on the same soil with different methods. Since phosphorus in soils is present in different forms and compounds, a wide variation in quantities of phosphorus extracted by different solvents should be expected.

Miller (30)[1] conducted a plot culture experiment on seventeen Maryland soils treated with five levels of super-phosphate. He reported that the greatest quantity of phosphorus was extracted by the method proposed by Miller and Axley (31) (0.03 N H_2SO_4 + 0.03 N NH_4F). The sodium bicarbonate method (36) released the least amount of phosphorus and the modified Truog (47), (0.02 N H_2SO_4) and the Bray No. 1 (6), (0.03 N HCl + 0.025 N NH_4F) methods were intermediate between them and removed approximately the same amounts of phosphorus.

Miller and Axley (31) found that their proposed method extracted the highest quantity of phosphorus compared to the modified Troug, Bray No. 1, and sodium bicarbonate methods.

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[1] Numbers in parentheses refer to literature cited.

Samonite and Mamoril (42) reported that for paddy soils the Ayres-Hagihara method (1), (0.002 N H_2SO_4 for extraction) extracted the highest quantity of phosphorus among Bray No. 1, Bray No. 2, Morgan, Olson and Peech methods. Ayres and Hagihara (1) found that their modification of the Troug method increased by 50% the amount of phosphorus extracted from moderately weathered soils and a nearly 20-fold increase for the highly weathered soils of Hawaii.

Cho and Caldwell (9) reported that the Bray No. 1 method extracts more phosphorus from acid soils than from calcareous soils and that the Bray No. 2 method extracts more phosphorus from alkaline soils than Bray No. 1. A 1% citric acid solution extracted more phosphorus from soils than the Bray procedures but the relative amounts extracted were similar to the Bray No. 1 procedure. The sodium bicarbonate procedure of Olson had a completely different pattern of relative amounts extracted, while the Morgan (32) procedure extracted much less phosphorus than either of the other three methods studied. The Morgan method also extracted much less phosphorus from acid soils than from alkaline soils. Water extraction removed the least amounts of phosphorus and the pattern of relative amounts extracted was nearly similar to that of Morgan method. Smith (44) reported that the 0.5 N sodium bicarbonate method of Olson extracted more phosphorus from the calcareous soils of western Kansas than the Bray methods.

Correlation of available soil phosphorus tests with crop yield and other dependent variables: — Much work has been done concerning the correlation of available phosphorus test methods with crop yield and other crop responses. Unless such correlations are studied a particular method cannot be accepted to be a better diagnostic procedure for a particular soil than any other method. Among many methods of correlating soil tests, one is the correlation of soil test values with percent of total uptake of the nutrient element in question. Another procedure used is to study the probability of obtaining a profitable increase in yield for a given fertilizer treatment and this is plotted against the soil test results (25). Here one uses an index of probability for the percentage of yield within a given range of soil test value that do or do not respond to determine the application of the soil amendment.

Miller and Axley (31) reported that 0.03 N H_2SO_4 + 0.03 N NH_4F dissolved more phosphorus from soils treated with rock phosphate than was readily available to plants as measured by the response of corn, wheat and red clover. The solvent 0.03 N H_2SO_4 alone gave a better relationship between phosphorus extracted and yield. Their proposed method gave the closest relationship with crop response. The Bray No. 1 and sodium bicarbonate methods gave the next best relationship with crop response and both were equally satisfactory for determining available phosphorus in soils.

Smith (44) reported that for calcareous soils of western Kansas the Bray No. 1 method gave a much higher correlation of phosphorus extracted versus percentage yield values than any other concentration of HCl or ratio of $HCl:NH_4F$ and 0.5 N sodium bicarbonate.

It has been reported (42) that the Bray No. 2 method gave the highest correlation with grain yield on paddy soils followed by the Olson, Peech, and Ayres-Hagihara methods which were considered reliable. Since the Morgan and Bray No. 1 methods did not correlate with yield, their applicability for paddy soils is doubtful. With phosphorus yield, the 0.5 N N HCO_3 method of Olson was best correlated followed by the Peech and Bray No. 2 methods.

The analysis data from 74 experiments from a wide variety of soils of the United States and Canada by 55 state and commercial laboratories using different methods and correlating the amounts of phosphorus extracted with "A" values, percentage yield, and Neubauer values showed that the Bray No. 1 was least affected by soil properties. The stronger acid extractants showed better correlation with phosphorus availability on soils of low pH and low cation-exchange-capacity (C) to anion-exchange-capacity (A) ratios (C/A). Weak acid extractants showed lower correlation coefficients on soils of low pH than on soils with high pH values. Results obtained by Morgan's method were not affected by soil grouping. The differences in correlations obtained from many laboratories using the same extractants emphasized the great influence of laboratory techniques on soil test results. The correlations between soil tests and Neubauer values were generally much better on soils of low pH and low cation/anion ratios than for soils of high pH and high cation/anion ratios (18).

Carbonated water, sodium bicarbonate and ion exchange resin were used to extract soil phosphorus by Rennie and McKercher (40). They reported that none of the data correlated with yield response from phosphorus fertilization. It was concluded that adsorbed phosphorus might possibly be included in, or influence the available soil phosphorus.

Nagata and Muramatsu (33) reported that the amounts of phosphorus extracted by 0.2 N HCl, Troug, Olson and Bray No. 1 methods from acid soils, pH 4.4 - 4.6 (CaO, 0.05%), correlated well with the amount of phosphorus adsorbed by barley plants. But with improved soils, pH 6.0 - 6.2 (CaO, 0.1%), good correlations between phosphorus extracted and phosphorus adsorbed by plants was found only with 0.2 N HCl. Both groups of soils were treated with different phosphate compounds. The extractions were performed on portions of uncropped soils. Plants grown on soils with 1.0% CaO adsorbed much more phosphorus than plants grown on soils with 0.05% CaO.

Cooke (11) obtained a very close relationship between soil tests and crop responses to phosphorus fertilizers, and concluded that soil tests can measure phosphorus availability. Miller (30) found that phosphorus removed by alfalfa had a closer relationship with the phosphorus extracted by different methods than with the yield of alfalfa.

Boyd (5) found that the Olson method was more satisfactory than any other method on calcareous and peaty soils. Few sites with a high phosphorus value by this method gave a large response to phosphorus fertilizers. The Morgan and citric acid methods were satisfactory for organic soils while the 0.3 N HCl and acetic acid methods were not acceptable. He also reported that the modification of Morgan's reagent (acidified NH_4Ac) showed no improvement over the normal method.

Factors other than the soil phosphorus content affecting soil test-yield correlations: — Many climatic and soil conditions influence soil test-crop response correlations. These factors affect the phosphorus availability and its uptake by plants.

Yield responses of wheat due to application of phosphorus were related to the available phosphorus prior to seeding, soil moisture at seeding, and the soil moisture at seeding time plus precipitation received from tillering to heading (12). The results suggest that if crop production is to be successful in dryland areas, the soil phosphorus test values in the medium range should be evaluated in terms of expected moisture supplies. Powers et al. (37) reported a 0.73 correlation coefficient between moisture and effect of phosphorus on yield, indicating that about 50% of the variation in yield on medium phosphorus soils was accounted for by the variation of soil moisture. According to Powers et al. (37), several investigators conducting fertilizer experiments with wheat on dryland soils reported conflicting results. In these studies chemical soil tests frequently failed to correlate with fertilizer responses in wheat fields, indicating that other factors are also important in regulating fertilizer responses in moisture deficient regions.

Eck and Stewart (14) found that climatic and agronomic variables are more closely related to yield response of winter wheat than is sodium bicarbonate-extractable P_2O_5. Data from 53 experiments (covering several years) with winter wheat in western Oklahoma show that results of soil tests for phosphorus alone, though related to yield, are of little value in predicting the yield response of wheat to phosphorus under dry land conditions. The magnitude of the correlation coefficient indicated that soil moisture at planting time was as closely related to yield response to phosphorus as was the soil test values. Consideration of precipitation, soil moisture at planting, temperature during ripening period, yield level, and date of seeding along with soil test values improved the estimate of expected response to phosphorus. Even with all these variables considered, prediction of yield response based exclusively on a phosphorus soil test would be quite hazardous (14). However, if moisture were adequate the phosphorus soil test value versus yield would probably be highly significant.

The soil type apparently determined to a large extent the relationship between soluble phosphorus and yields of alfalfa (30, 25). The correlation coefficient for the Bray No. 1 method ranged from 0.120 to 0.885 depending upon the soil type being studied. In a number of cases the soils which gave a poor correlation were high in extractable phosphorus and showed no response to phosphorus application.

The amounts of super-phosphate needed to establish similar levels of chemically available phosphorus in pot culture varied considerably (30). Properties such as texture and types of clay minerals influenced the phosphate absorbing properties of soils. The super-phosphate required to establish 60 pounds of soluble phosphorus in Beltsville loam and Montalto clay loam varied by more than 1500 pounds per acre although each soil had the same original Troug phosphate content.

Baumgarnde and Barber (2) stated that another reason for unsatisfactory correlation of soil test values and crop response is the inclusion of data from two or more distinctly different populations. To investigate the reliability of a soil testing procedure, there must be a standard of measurement for the amount of nutrient in the soil available to the plant. By greenhouse and field experiments they found that both the drainage profile number and catena affected the phosphorus regression to the yield, but had little effect on potassium.

Ferguson and Gorby (15) investigated three great soil groups of the Black Chernozemic soil at two different elevations for crop yield and plant response to phosphorus. They concluded that a large portion of the total variance was attributable to fields and to interaction between fields and soils. They found that the lower topographic sections required twice as much phosphorus to maximize profits from wheat. A south facing slope gave a different response than a north facing one due to micro-climate variation. The degree of slope and size of drainage area would also affect the relative hydrological and microclimatical situations at the various sites.

Ayres and Hagihara (1) reported a direct relationship between the supply of available phosphorus and the degree of weathering of Humic Latosol great soil groups. They stated that by keeping the volume of H_2SO_4 constant and using different amounts of soil (2, 5, 10, 15 and 20 grams) the amount of phosphorus extracted per unit weight of soil from 20 grams of soil was 10 to 50 times smaller than from 2 grams of soil. They also found that with the majority of soil profiles the levels of available phosphorus diminished with depth. Bigger et al. (3) reported that phosphorus applied to the soil remained in the surface soil while the applied potassium was found in the 10 to 16-inch depth.

The effects of season and site factors, some undetermined, on crop response to fertilizer phosphorus were large enough to prevent a precise comparison of methods (48). For slightly acid to nearly neutral arable soils several methods could be of equal value. With slightly calcareous soils the $NaHCO_3$ method seemed more reliable. For soils containing $CaCO_3$ this method avoids the error due to dissolving unavailable phosphorus from mineral phosphates and phosphatic chalk. This error can occur when extractants with acidity greater than pH 4.0 are used. Barley, wheat, sugar beets, swedes, and kale gave good responses to superphosphate on soils with $NaHCO_3$ values below 1 mg P/100 gm soil. Increases in yields would be small with soil test values above this amount.

Extractable soil phosphorus forms and their relation to different solvents and soil conditions: — In general, phosphorus in the soil is found in organic and inorganic forms. The inorganic form is mainly as aluminum, iron, and calcium phosphates (8, 37). Cho and Caldwell (5) found that iron and aluminum phosphates were abundant in acid soils while calcium phosphate occurred in alkaline soils. Soils having a pH near 7.0 had equal proportions of all three forms, though slightly more iron and aluminum than calcium phosphate was present. Organic phosphate was shown, in general, to agree with the organic matter content with some deviation. They also reported that the phosphorus fixing capacity of soils increased with increasing acidity.

Bishop and Barber (4) stated that in alkaline limed soils calcium phosphate dominated while in acid unlimed soils iron and aluminum phosphates dominated. Treating the soil for pH change did not soon change the type of phosphorus compound present. They also reported that calcium phosphate compounds were soluble in acid extractants and aluminum phosphate compounds in alkaline extractants while certain iron phosphate compounds could be soluble in either acid or alkaline extractants. Bishop and Barber concluded that soils were heterogeneous with respect to the phosphorus compounds present and that neither an acid nor an alkaline extracting solution is likely to give results which correlate highly with crop response to phosphorus fertilization. Instead, it would seem that a combination of both acid and alkaline extractants would give results that would be highly correlated with yield. A multiple correlation coefficient of 0.851 was obtained for acid soluble plus alkali soluble phosphorus; simple correlations of 0.557 for acid-soluble and 0.657 for alkali-soluble phosphorus were obtained (4).

Retention of phosphorus by soils: — Wild (52) gives the following definitions regarding phosphorus retention terminology:

'Phosphate' refers to the anions which are formed from the dissociation of orthophosporic acid or any of its salts.

'Phosphate sorption' or 'phosphate retention' are used synonymously and are taken to mean the removal of phosphate from solution by soil or by a soil constituent. No particular mechanism is implied.

'Phosphate adsorption' and 'phosphate absorption' are taken to mean the retention of phosphate at a surface, and within a solid phase, respectively.

'Phosphate fixation' is used to describe any change that the phosphate undergoes in contact with the soil, which reduces the amount that plant roots can absorb. It is understood that plant roots active in nutrient absorption can penetrate into the locality of phosphate, that is the phosphate is not positionally unavailable to the roots.

According to Wild (52), the retention of phosphate was first demonstrated by Way in 1850. Liebig (52) had anticipated the results 10 years earlier stating (in regard to soluble phosphates) that "in a few seconds the free acid unites with the bases contained in the earth and a neutral salt is formed in a very fine state of division." Way had found that all the phosphate was retained when a solution of sodium phosphate in water, and guano in dilute sulfuric acid, were poured over a layer of calcareous soil. After testing the drainage water for water-soluble phosphorus from a fertilized field, he found a very small amount of phosphorus and concluded that insoluble calcium phosphate was formed.

According to Wild (52), Dayer analyzed the continuous-wheat plots at Rothamsted and found that most of the phosphate that had been applied and not been removed by plants, was still present in the top 9 inches of soil.

Wild (52) summarizes the factors effecting phosphate retention as follows.

1. Mechanical composition of the soil: — Most of the retaining power of soil for phosphorus lies in its finest mechanical fractions, especially clay.

2. Phosphate concentration: — The greater the ratio of

phosphate to the soil, the greater is the retention of phosphate.

3. Time and temperature: — The retention of phosphate comes to completion very slowly, if at all. With soil and with soil clay the initial stages of reaction proceed rapidly but the reaction, although getting slower, continues for many weeks. The solubility of soil phosphates in dilute acids after phosphate has been added to the soil has been shown to decrease with time.

The effect of temperature on the retention of phosphate under non-sterile conditions depends on the relative rates of mineralization of organic matter, thus allowing release of phosphate and the adsorption of phosphate by microorganisms. Under sterile conditions phosphate retention increases only slightly as the temperature increases from 25° C. to 35° C. If the temperature is increased up to 100° C., the reaction proceeds much more rapidly.

4. Effect of salts: — Most salts decrease the solubility of phosphates.

The primary object of defining the form of phosphorus in soils is to be able to predict the pattern of phosphorus supply to the growing plants. Rennie and McKercher (40) concluded that phosphorus in the soil is probably not fixed, but is adsorbed as a mono-molecular layer on the surface of the soil colloid. The percentage saturation of the adsorption maximum may serve as a measure of the capacity of soils to supply phosphorus to the soil solution. The equilibrium concentration of phosphorus in a soil suspension may be used to estimate the degree of saturation of phosphorus on the soil colloid.

Koshy and Brito-Mutuayam (27) investigated the relative amounts of phosphorus reverted to different chemical forms of soil phosphorus.

They reported that the results obtained were inconsistent with the adsorption theory of phosphorus fixation which implies a far greater retention by the clay than by the silt. Their findings were in favor of the chemical precipitation theory but did not totally exclude the possibility of adsorption by clay minerals of the soil.

Chang and Chu (8) reported that in the soil pH range of 5.3 to 7.5 the first stage of fixation of added soluble phosphate occurred on the surface of the solid phases with which the phosphate came in contact, and that the relative amounts and kinds of phosphate formed depended on the specific surface area of the solid phases associated with aluminum, iron and lithium. In time the aluminum and calcium phosphates then gradually changed to less soluble iron phosphate, the rate of transformation increasing with moisture content of the soil. It was found that super-phosphate applied to a soil over 31 years was mostly retained in the form of iron phosphate with aluminum phosphate next, and the least retained as calcium phosphate (8).

Wiechmann (51) found that phosphorus accumulation was restricted to the plow layer in long term field trial soils which had received increasing applications of basic slag or super-phosphate. In plow layers, he reported, 20 to 50% of the total phosphorus was originally bound and was independent of fertilization. Of the inorganic phosphorus fixation, only the $Al\text{-}PO_4$, $Fe\text{-}PO_4$ and $Ca\text{-}PO_4$ contents were influenced by fertilization, and the accumulation of $Al\text{-}PO_4$ and $Fe\text{-}PO_4$ was most important in all plots.

Manning (29) studied the forms of phosphorus in a Brown-Podzolic silt loam after 65 years of phosphate fertilization. He reported that increased applications of phosphates resulted in greater amounts of extractable phosphates regardless of the source. Where super-phosphate was applied 47 to 66% aluminum phosphate was extracted, and where rock phosphate was applied this amount was 26 to 39%. The iron and calcium phosphates increased to a lesser extent. Rock phosphate treatments increased the calcium phosphate fraction. Manure application followed a similar pattern of aluminum phosphate formation of applied phosphorus as did super-phosphate. Occluded and organic phosphate fractions were not greatly affected by various levels of applied phosphate. Summation of extracted organic and inorganic phosphate did not equal the total phosphorus. This "unextractable" fraction is believed to be tightly bound forms, not solubilized by the acid extractions or possibly held as non exchangeable "lattice" phosphate. Lime treatments somewhat decreased the amount of aluminum phosphate.

Kurtz et al. (28) reported that phosphate adsorbed by the soil increased with the concentration of phosphate in solution and that the amount absorbed gradually approached a level above which there was little further adsorption regardless of increase in concentration. Phosphate adsorption was much greater in the presence of soluble salts. Soil:solution ratios did not show any difference in phosphate adsorption. It was assumed that the water-soluble form was the only form usable by plants. It is seen that even by this extremely conservative standard much of the added phosphorus is recoverable after 3 years. It was found (28) that the water solubility of added phosphate decreased with time and the reaction by which phosphate was removed from solution was not complete after any period of time. At the end of 3 years, a significant portion of the original portion was removeable by three to four water extractions. Even small phosphate additions increased the phosphate which the soil could supply to the solution. Nearly all of the added phosphate which was not recovered in the water-soluble fraction was found in the adsorbed fraction.

Kurtz et al. (28) also found that the chloride, sulfate, thiocyanate, acetate and borate ions have low replacing ability for phosphate and remove amounts which are similar to or smaller than the amount removed by water alone. On the other hand bicarbonate, citrate, oxalate and fluoride ions are much stronger. The fluoride ion is outstanding in the ease and rapidity with which it replaces phosphate. The replacing abilities are related to the tendency of the different ions, in comparison with phosphate, to form stable complex ions in the clay mineral lattice.

Olomu (35) treated some Nigerian soils with mono-basic ammonium phosphate and di-basic ammonium phosphate and found that the same amount of phosphorus were fixed in both treatments but more of the fixed dibasic ammonium was recovered. The phosphorus was mostly found as aluminum phosphate. The total amounts of phosphorus fixed as aluminum, iron and calcium phosphates increased when they were allowed to react from three days to thirty days. Highly significant correlations were found between the total amounts of phosphorus fixed and the exchangeable aluminum. Olomu (35) also found that for the upland soils most of the inorganic phosphate was in the form of iron phosphate, followed by the aluminum and calcium phosphates. Whereas, in lowland soils most of the active phosphate was in the form of aluminum phosphate followed by iron and calcium phosphate. This determination indicates that these lowland soils had been subjected to less weathering than the upland soil.

Westerman (50) found that when concentrated super-phosphate was applied to the wheat fields the content of $AlPO_4$ increased. Iron, calcium and water-soluble phosphates also increased but to a lesser extent. He reported a significant increase in the yield of spring wheat as the amounts of applied phosphorus were increased.

Smith et al. (44) reported that the response to rock phosphate did not occur on soils characterized with pH values of 7.0 or higher but the response increased as the soils became more acid in reaction. They found that both ferric and aluminum phosphates were more soluble in the presence of dilute acid and fluoride than in dilute acid alone.

Samonte and Mamoril (42) reported that aluminum, calcium, and iron phosphates gave significant correlations with the available phosphorus of most soil test methods.

Chu and Caldwell (9) obtained high correlation values from Bray No. 1 and 2 methods with aluminum and iron phosphates. A similar correlation was reported with citric acid. They also found that the $NaHCO_3$ method had a high correlation with aluminum and iron phosphates but did not give a negative correlation with calcium phosphate. The Morgan method correlated well with calcium phosphate. Water-soluble phosphate was much lower than the Morgan phosphorus values but the Morgan test gave lower correlation coefficients than the water-soluble phosphorus data.

CHAPTER III

MATERIAL AND METHODS

The History of the Magruder Plots.[1] The Magruder plots, on which this study was conducted, were originally broken from virgin prairie in 1892. They are a part of the original experimental wheat plots started by A. C. Magruder to study the ability of the soil to produce wheat without fertilization. From 1893 through 1898 a 1.25 acre experiment receiving no fertilizer was conducted. In 1899 the plot was divided into two sections, one with manure and the other half with no treatment and continued as such until 1929. Beginning in 1930 each half was divided into 5 plots and fertilized with 10 different treatment combinations. The arrangement of the 10 plots in their original locality is shown in Fig. 1. In 1930 a strip of land 100-feet wide across the east end of the plots was removed from the experiment to make way for Murray Hall, a girls dormitory on the Oklahoma State University campus. In 1947, the construction of Stout Hall on the remaining area was initiated and the Department of Agronomy transferred the plots to their present location on the Stillwater Agronomy Research Station about one mile east of the original location by the following procedure:

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[1] The information about the history of the plots, treatments, yields and soil analysis data of 1938 was collected from Oklahoma State Univ. Experiment Station Bull. B-531, Processed Series of Annual Progress Reports of the Station on Wheat Fertilization Research, and records kept in the Station files.

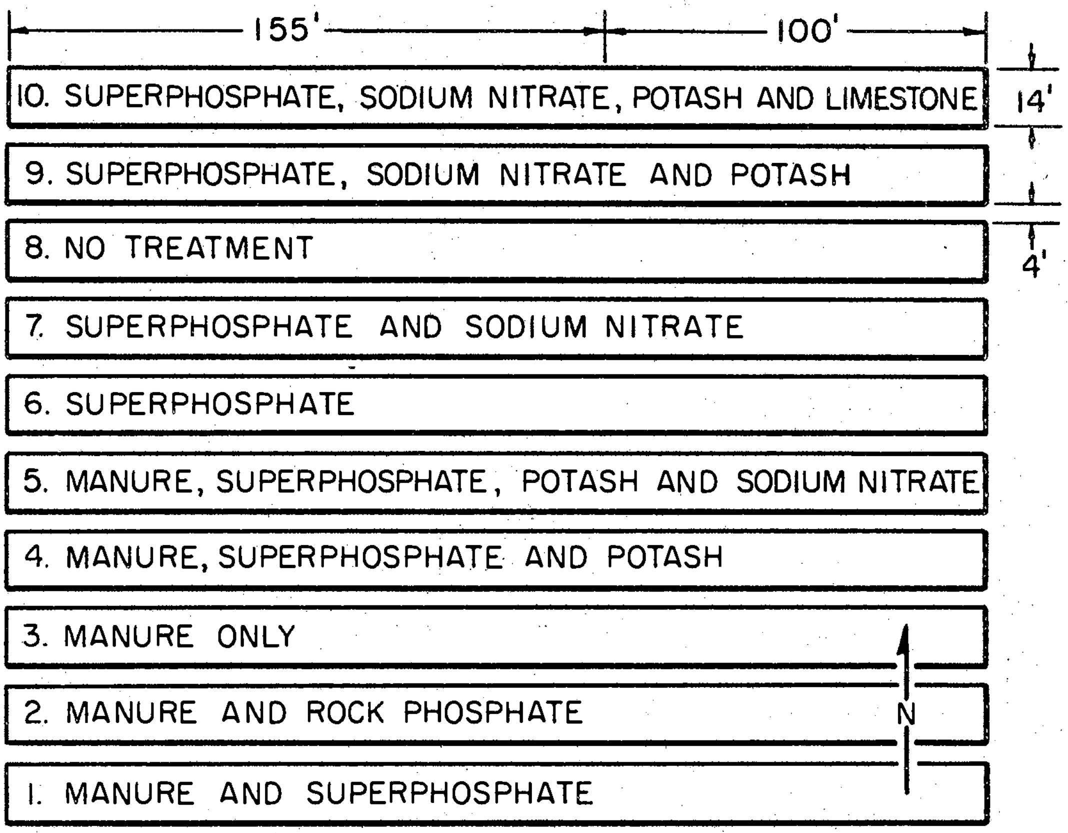

Figure 1. The Arrangement of the Magruder Plots in Their Original Location before 1947.

The surface (0" - 8") and sub-surface (8" - 16") soils from 100 x 21.5 feet near the center of each plot (Plots 3, 6, 7, 8, 9 and 10) of the original location (Fig. 1) were piled up separately and trenches were dug to the proper depths and areas at the new location for each plot. The sub-surface soils were first layered in the bottom of the trenches and leveled. The top soils were then spread evenly over the sub-surface soils. A four-foot border of undisturbed soil was left between each pair of the new plots. The soil below 16 inches in the new location is very similar to that of the previous location. The present arrangement of the plots is illustrated in Fig. 2.

<u>The Treatment of the Plots</u>. The six plots that were transferred have had the following treatments:

1. Nothing has been added to Plot 8 (check) since the land was broken from virgin prairie in 1892.
2. Plot 3 (manure) has had only barn yard manures as follows:

   From 1899 to 1911 4.5 tons/acre/year on the average.
   From 1912 to 1936 3.0 tons/acre/year of moist material.
   In 1936 4.0 tons of dry manure/acre.
   From 1941 to 1966 manure equivalent to 120 lbs. of N/acre (every fourth year)
3. Plots 6, 7, 9 and 10 received 150 lbs/acre/year of superphosphate from 1930 to 1966 and it was applied in the fall.
4. Plots 7, 9 and 10 received the following nitrogen treatments:

   From 1930 to 1945 16 lbs. N/acre/year as $NaNO_3$.
   From 1946 to 1966 100 lbs. ammonium nitrate/acre/year applied in the spring.
5. Plots 9 and 10 received 50 lbs./acre/year muriate of potash

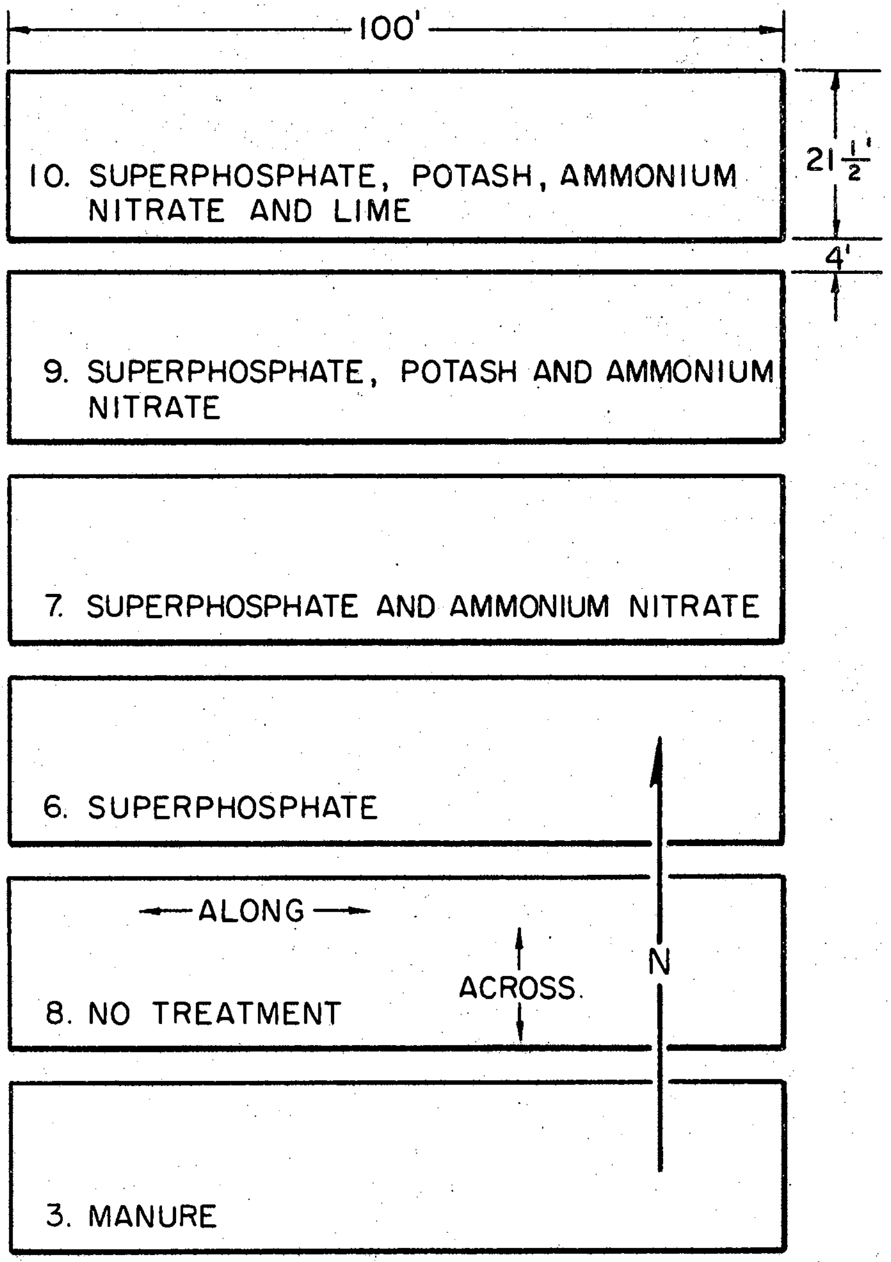

Figure 2. The Arrangement of the 6 Transferred Magruder Plots at the Present Location Since 1947. (For soil sampling purposes the subplot No. 1 was started at north-west corner and ended with subplot No. 40, south-east corner of each plot.)

applied in the fall.

6. Plot 10 received 6000 lbs./acre of coarse limestone screenings in 1929 and 4000 lbs./acre of ground limestone in 1954.

Sampling procedure. The six existing plots are arranged as manure, check, P, NP, NPK, and NPK + Lime plots (Fig. 2). Each plot is 21.5 feet wide and 100 feet long. The plots lie east and west lengthwise.

For the purpose of soil sampling each main plot was divided lengthwise into 4 strips and each strip was subdivided crosswise into 10 subplots. Thus each main plot was divided into 40 subplots of 4' x 10' each. There was a border of 16.5 inches for each main plot.

The 40 subplots in each main plot were sampled at random using a hand auger. Five borings were taken and the samples were collected from 0" - 6" and 6" - 12". In other words, a composite of 5 borings would give 2 samples (from the 2 depths) per subplot, and 80 samples per main plot. Sampling was done during the early spring of 1966.

Processing the samples. The soil samples were air dried, crushed and passed through a 20 mesh sieve.

Soil testing methods used. The Bray No. 1 method (6) was used for available phosphorus content. For the available potassium the ammonium acetate method was used which involved 1 hour shaking and the use of a Beckman DU Flame Spectrophotometer with an oxy-hydrogen burner and photomultiplier, and for pH determination a Beckman Zeromatic pH-meter was used to determine the pH of a water-soil saturated paste.

CHAPTER IV

RESULTS AND DISCUSSION

Variations of Available Phosphorus Test Values. Available phosphorus content of soils depends upon several soil and climatological factors as well as soil treatments. Since the plots in this study have been treated differently in one way or the other, the available phosphorus test values among the plots were significantly different at the 1% level. Table 1 shows the analysis of variance of available phosphorus variations among plots, between surface soil and subsoil, variations across and along the plot design, the interaction of plots with depth, and the interaction of rows with columns of the plot design.

The significant variation in available phosphorus test values across the columns might be due to application of phosphorus fertilizer in bands and then by the yearly inversion of the soil while plowing to bring about some mixing with adjacent soil while the center two columns were not affected. Since borings were made at random within the subplots, the positions of the borings were not considered. Thus, since the fertilizer phosphate was positioned along paralled lines, the lack of uniformity that resulted in test values across the plot layout was probably due to mixing of fertilizer with unfertilized soil and mixing of unfertilized soil with the fertilized plot soil.

The variation along the rows was not significant for available soil phosphorus test values.

TABLE I

ANALYSIS OF VARIANCE OF AVAILABLE PHOSPHORUS DISTRIBUTION ON THE WHOLE LAYOUT OF THE MAGRUDER PLOTS, 1966

Source	d.f.	M. S.	Calc. F.
Treatment (Plots)	5	17862.715	144.356**
Depth	1	25513.775	206.188**
Blocks (Across)	9	110.510	0.893N.S.
Column (Along)	3	1406.793	11.368*
Treatment X Depth	5	2268.397	18.331**
Treatment X Column	15	1279.478	10.340**
Residual	441	123.740	

* Significant at the 5% level
** Significant at the 1% level
N.S. Not significant

The variation for the test values of available phosphorus between 0" - 6" and 6" - 12" was highly significant. Being immobile due to soil fixation and precipitation, phosphates do not move down as far as some of the other anions do. Bigger et al. (3) reported that phosphorus applied to the soil remained at the surface soil.

The analysis of variance of available phosphorus test values within the plots (Table II) shows that there were no significant variations along the plots individually in any depth. Across the plots the check plot was highly significant for 0" - 6" depth and significant at the 5% level for 6" - 12" depth. This would be due primarily to the "border effect." Also the NPK + Lime plot was significant at the 5% level for 0" - 6" depth and the manure plot and P-plot were significant at the 5% level for 6" - 12" depth in available phosphorus test values across the

TABLE II

THE ANALYSIS OF VARIATION OF AVAILABLE PHOSPHORUS TEST VALUES VARIATION WITHIN MAGRUDER PLOTS, 1966

Manure Plot 0" - 6"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	70.110	1.028 N. S.
Column	3	302.712	4.442 N. S.
Error	27	68.144	

Manure Plot 6" - 12"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	16.959	0.317 N. S.
Column	3	619.282	11.559 *
Error	27	59.803	

Check Plot 0" - 6"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	31.747	1.175 N. S.
Column	3	1116.764	41.345 **
Error	27	27.010	

* significant at the 5% level
** significant at the 1% level
N. S. not significant

Tabulated F

For 9 and 27 d.f., 2.88 at the 5% level and 4.69 at the 1% level.
For 3 and 27 d.f., 8.62 at the 5% level and 26.55 at the 1% level.

TABLE II (Continued)

NP - Plot 6" - 12"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	61.432	0.561 N. S.
Column	3	26.525	0.242 N. S.
Error	27	109.455	

NPK - Plot 0" - 6"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	113.475	1.036 N. S.
Column	3	51.043	0.466 N. S.
Error	27	109.461	

NPK - Plot 6" - 12"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	59.867	1.038 N. S.
Column	3	49.765	0.863 N. S.
Error	27	57.630	

NPK + Lime Plot 0" - 6"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	173.154	1.252 N. S.
Column	3	1561.295	11.290 *
Error	27	138.289	

TABLE II (Continued)

Check Plot 6" - 12"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	10.897	0.439 N. S.
Column	3	570.411	23.006 *
Error	27	24.794	

P - Plot 0" - 6"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	213.803	0.488 N. S.
Column	3	3191.803	7.289 N. S.
Error	27	437.855	

P - Plot 6" - 12"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	212.989	1.625 N. S.
Column	3	2038.875	15.564
Error	27	130.997	

NP - Plot 0" - 6"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	183.243	1.394 N. S.
Column	3	125.086	0.952 N. S.
Error	27	131.393	

TABLE II (Continued)

NPK + Lime - Plot 6" - 12"

Analysis of Variance

Source	d.f.	M. S.	Calc. F.
Block	9	158.118	2.192 N. S.
Column	3	375.576	5.208 N. S.
Error	27	72.104	

plots. These variations could be due primarily to fertilizer placement, plowing effects, randomization, sampling error, and laboratory error.

The Relations of Available Soil Phosphorus and Available Soil Potassium Test Values and pH Values with Yields of Wheat Grain. The available phosphorus test values for the top soil had a correlation coefficient of 0.416 (for 20 years, 1947 - 1966) with average yields, which is not significant. Since the plots were treated differently and the available phosphorus was not the only variable factor in the plots, a high correlation is not necessarily expected. Cooke (10) states that

> Chemical laboratory work is usually with fine soil and reagents attack the whole soil, but in the field, soils may have a coarse or fine structure, roots may grow deeply or shallowly; the actual total volume of soil used depends on texture and structure, on weather, and on the crop characteristics, such as its root range and growing season. Close correlation between laboratory measurements and field crop performance is therefore impossible and should not be accepted.

The Bray No. 1 soil test values for available phosphorus is plotted against the 20 years average yields, yields of 1965 and yields of 1966 (Fig. 3). All three graphs have about the same general pattern. It can be clearly observed from these graphs that the phosphorus plot having the highest value for available phosphorus had the lowest yield with

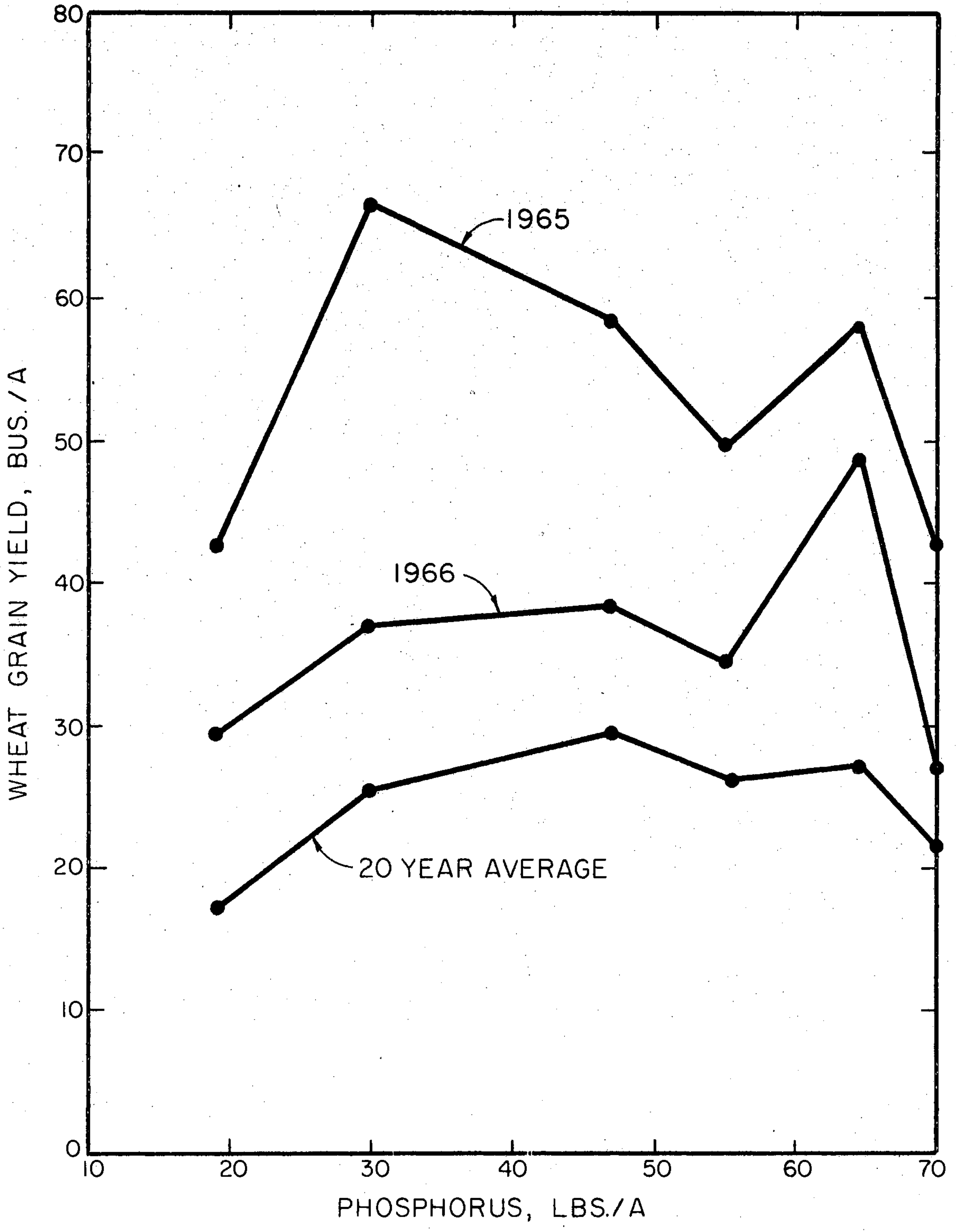

Figure 3. Bray No. 1 Method Soil Phosphorus Test Values Vs. 20 Years Average, 1965 and the 1966 Yields of Wheat Grain of the Magruder Plots.

the exception of the check plot. This confirms that not only the available phosphorus is responsible for the yield, but other nutrients and factors have an obvious effect on yield. The higher correlation coefficients of pH and available potassium with yield, 0.798 and 0.501 respectively, as compared to the available phosphorus value with yield may also reflect the effect of these two variables on yield. The same picture is noticed when available phosphorus values from the 0.2 N H_2SO_4 extractant as determined in 1938 (23) is plotted against 8 years (1931 - 1938) average yields, yields of 1937 and those of 1938 (Fig. 4). In this case the manure plot had the highest value for available phosphorus followed by the phosphorus plot both which had the lowest yields except for the check plot.

The 20 years (1947 - 1966) average yield for P-plot was 21.80 bu/A while for the NP plot it was 27.28 bu/A. Since, in this experiment, there was no independent N-only treatment we can not say whether this increase was due to the effect of N alone or whether there was a relation between uptake of phosphorus and N supply. However, several workers (13, 17, 21, 22, 34, 43, 53) have reported that nitrogen had increased the uptake of fertilizer and soil phosphorus for many field crops and vegetables. Grunes (20) listed the various reasons for the effect of nitrogen on phosphorus uptake:

1. Nitrogen increases root growth and foraging capacity of roots for phosphorus.
2. Nitrogen may effect plant metabolism and the ability of roots to absorb phosphorus.
3. Top growth of plants is increased thus increasing the requirement for phosphorus.

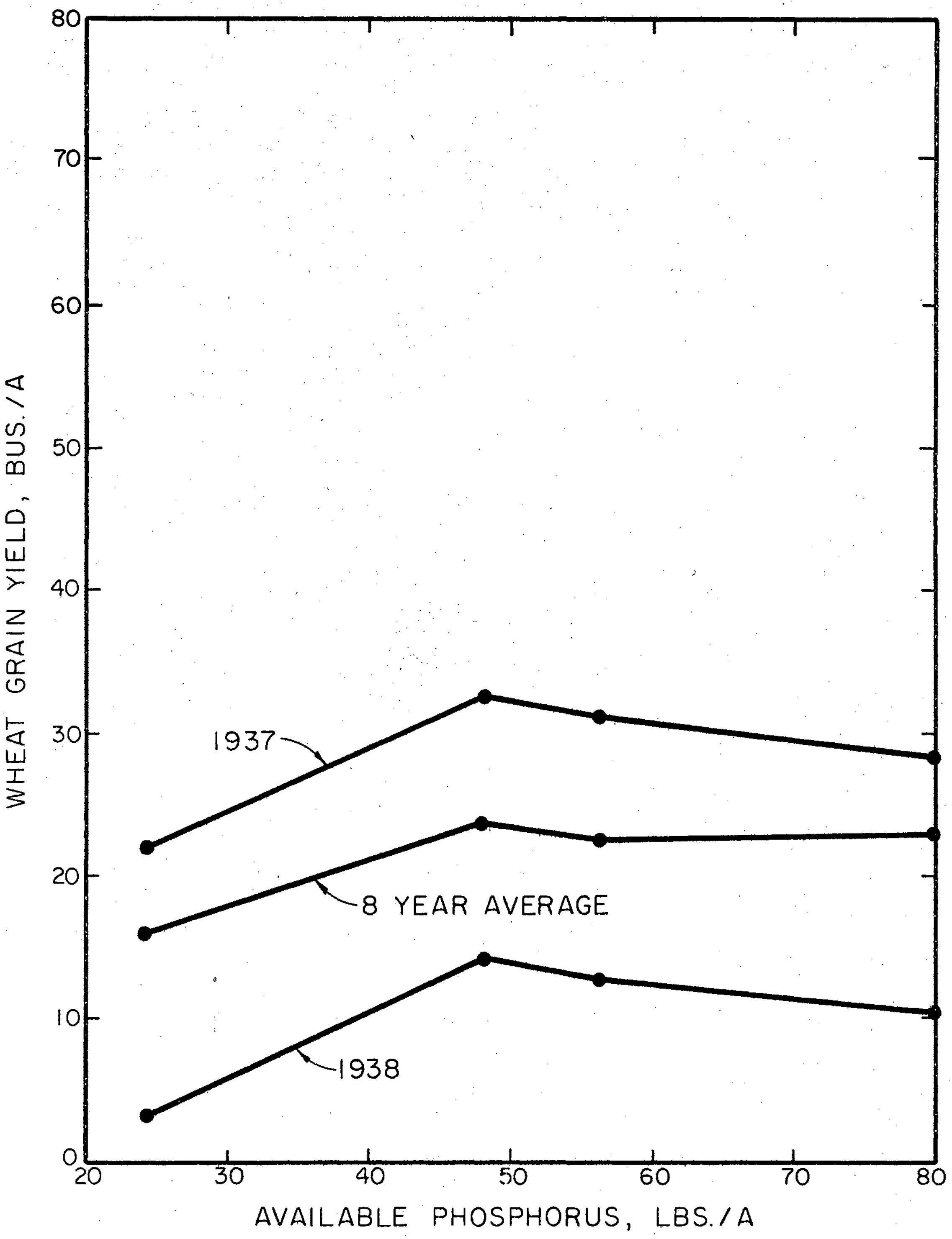

Figure 4. 0.2 N H_2SO_4 Method Soil Phosphorus Test Values Obtained in 1938 Vs. 8 Years Average (1930-1938), 1937 and 1938 Yields of Wheat Grain of the Magruder Plots.

4. Nitrogen compounds may have significant salt effects on phosphorus solubility. (Ammonia sources are generally more effective than nitrates.)
5. Residual acidity of the fertilizer may increas phosphorus availability.

It has been reported (41, 46) that treating rock phosphate with nitric acid (nitrophosphate) in most cases had an equal effect on yield of cotton, small grains and corn to phosphates applied as commercial-type fertilizer mixtures or as concentrated super-phosphate.

The manure treatment plot of the Magruder plots gave an average yield of 25.74 bu/A which is considerably greater than that of the phosphorus only plot. Increasing the organic matter in the soil probably increases yields by producing a better soil structure, by providing nitrogen and by preventing P fixation. Kardos (26) states that organic matter decreases phosphorus fixation because organic compounds that are mostly ionic in character compete with phosphate in polar adsorption phenomena; by chelation of Al and Fe by hydroxy acids such as tartaric, citric, malonic and malic, thus preventing Fe and Al from forming insoluble precipitates with phosphate; and by decreasing the probability of phosphates competing for isomorphic replacement in the clay lattice.

Although the phosphorus test value for the manure plot was 29.48 lbs./A, which is considerably lower than the other plots except the check plot, the yield of wheat from the manure plot was quite close to the plots with higher phosphorus test values. Drake (12) states that a more fundamental explanation of the role of soil organic matter in phosphorus uptake is that the organic anions produced by microorganisms complex the Al, Ca and Fe and thereby increase the solubility of the relatively insoluble soil phosphates. The important solubilizing effects of organic anions on relatively insoluble forms of soil phosphates helps explain the frequent inability of chemical soil tests to predict the phosphorus supplying power of the soil. Organic matter also increases the K uptake (50).

The NPK - plot gave an average yield of 26.30 bu/A. and the NPK + Lime plot gave 28.42 bu/A. which was the highest yielding of the Magruder plots. It appears that the original supply of K in this soil is high. But if the data of exchangeable K from 1938 and from 1966 are compared (Table III and Fig. 5) it can be observed that the values for available K in 1966 are lower in all plots which did not receive K fertilizer than the values of exchangeable K in 1938. The available K values are lower than exchangeable potassium values in any particular set of soils. Crops take up much potassium and the amounts that are exchangeable can be removed by one heavy yield; the rate of release of potassium from the useful, but non-exchangeable, reserves determines whether potasssium fertilizers must be used heavily or lightly (10).

Grissinger and Jeffries (19) determined that acid-soluble potassium in the soil was maintained at a constant value either by fixation of exchangeable potassium when an excess was present or by release of potassium from a difficultly available supply when deficiency or low levels of soluble K occurred. He reported the exchangeable K values of three check treatments to be 275, 253 and 104 lbs./A, which were related to the order of acid soluble values that were 470, 430 and 375 lbs./A. It was found (49) that added potassium and NH_4 would block the uptake of non-exchangeable potassium by plants but the blocking effect of NH_4 addition on uptake was short-lived because the NH_4 was quickly nitrified.

TABLE III

THE VALUE OF EXCHANGEABLE POTASSIUM, AVAILABLE POTASSIUM, AVAILABLE PHOSPHORUS AND pH FOR YEARS 1938 AND 1966

	1938			1966		
Plots	lbs./A Available P 0.2 N H_2SO_4	lbs./A exchangeable K	pH	lbs./A Available Bray No. 1	lbs./A Available K	pH
Manure	80	640	5.6	29.98	360	5.39
Check	24	480	5.1	19.42	284	5.36
P	56	480	5.1	69.79	328	5.25
NP	56	460	5.1	64.09	369	5.17
NPK	48	420	5.1	55.24	449	5.67
NPK + L	48	400	6.4	47.01	391	6.17

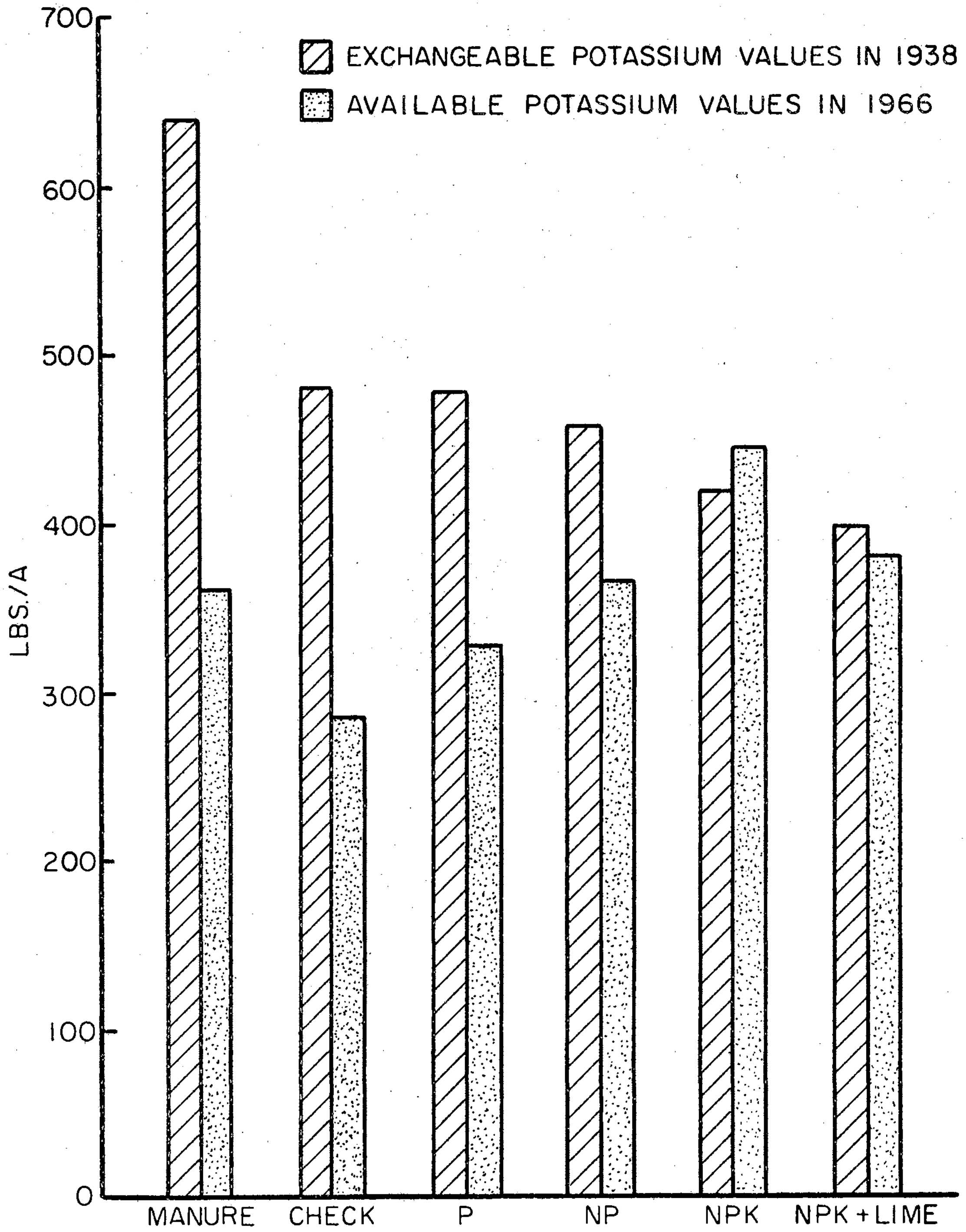

Figure 5. The Comparison of Soil Potassium Test Values in 1966 to Soil Exchangeable Potassium Test Values in 1938 of the Magruder Plots.

In the present study the applied potassium probably had an effect on raising the pH value of the soil in NPK plot but the average yield was lower than the NP-plot. The NPK + lime plot had the highest average yield. The higher pH value of the NPK plot and a lower average yield than NP-plot can be accounted for by the unfavorable effect of K being dominant on the exchange complex or decreasing the availability of calcium. Gammon (18) reported that many secondary advantages occurred from the maintenance of a favorable pH but the substitution of Na or K for any considerably portion of the Ca required to maintain a favorable pH may have a more unfavorable effect on root development than the untreated acid soil. He stated that the relative quantity of Ca present is more important and essential for root development. The higher yield and pH of NPK + lime plot in the present study confirms Gammon's findings.

Liming also effects the release of phosphorus and K. Pratt et al. (38) reported that incubation of samples of the same soil with various cations in the exchange complex indicated higher K release from non-exchangeable forms with Ca rather than with H. Exchangeable Ca would increase K uptake of plants (24).

Calvert et al. (7) reported that with freshly acid-washed clay separates P retention generally increased with increased Ca saturation, whereas phosphorus retention for clays aged after acid washing greatly decreased as Ca saturation increased. Ragland and Seay (39) found that at a rate of 100 PPM P_2O of applied phosphorus the retention and fixation of phosphorus by four initially acid saturated clays increased as the percent Ca saturation reached 60%. When phosphorus was applied at the rate of 800 PPM to the clay, fixation decreased with increasing percentage of calcium saturation. Approximately 90% of the phosphate will be fixed by aluminum at pH 6.5 and 70% at pH 9.0. Less than 10% of phosphate precipitated by iron and aluminum at pH 4.0 would be solubilized by increasing the pH to 6.0. But, no phosphate would precipitate in this pH range in the presence of citrate and certain other organic materials. This means that liming has less direct effect on phosphorus availability than indirect effect produced by creating more favorable conditions for increased production of plant residues and better microorganism activity (12). It can be seen in Table IV that lime did not increase the available P value but the wheat yield for the NPK + Lime plot was the highest for the 20 year average.

Phosphorus showed a tendency to acidify the soil. The P and NP plots not treated with potassium or lime had the lowest pH values of all plots in 1966. The correlation coefficients between six phosphorus tests and pH values were all negative.

If we look at the relative values of available phosphorus and compare them to the yields (Fig. 3) it becomes obvious that it is generally higher where super-phosphate was applied. The comparatively low available phosphorus value for NPK + Lime plot might be due to Ca fixation and partly due to yield increase.

Yields as a whole were highly significant both with plots (treatment) and year (Table V). Soil and climate factors are greatly responsible for yield. In this study the plots were all treated differently thus providing different soil factors. The climatological conditions such as rainfall, temperature, etc. are variable from year to year as well as the insects, pests and bird damage factors. So there is no question of variation of yield among years. Table VI in the Appendix shows the yield data from 1930 - 1966.

TABLE IV

AVAILABLE PHOSPHORUS TEST VALUES OF 1938 BY 0.2 N H_2SO_4 AND OF 1966 BY BRAY NO. 1 METHOD AND THE WHEAT GRAIN YIELDS AS PLOTTED IN FIGURES 3 AND 4

Plots	lbs./A Bray No. 1 Phosphorus test values 1966	bu./A grain yields			lbs./A 0.2 N H_2SO_4 P-test values 1938	bu./A grain yields		
		20 years average 1947-1966	1965	1966		8 years average 1930-1938	1937	1938
Manure	29.98	25.74	66.4	37.1	80	22.99	28.3	10.2
Check	19.42	17.54	42.6	29.7	24	16.08	22.0	3.4
P	69.79	21.80	42.6	25.2	56	21.74	28.8	11.7
NP	64.09	27.26	58.0	49.0	56	23.28	30.3	11.7
NPK	55.24	26.30	49.4	34.5	48	24.28	32.2	12.4
NPK + L	47.01	28.92	58.4	38.1	48	23.41	32.5	14.1

TABLE V

ANALYSIS OF VARIANCE OF WHEAT GRAIN YIELDS FROM 1947 TO 1966 OBTAINED FROM A 72 YEAR CONTINUOUS WHEAT CROPPING AND LONG-TERM FERTILITY TREATMENTS

Source	d.f.	M. S.	Calc. F.
Treatments (Plots)	5	351.163	14.70 **
Years	19	625.242	27.31 **
Error	95	23.878	

** Significant at the 1% level

CHAPTER V

SUMMARY AND CONCLUSIONS

In this study the effect of a 72 years of continuous wheat cropping and long-term fertilizer applications on yield trends, soil available phosphorus and on soil reaction was investigated. The relation of chemical soil test data with grain yield was also studied.

From this investigation it may be concluded that:

1. It is possible to keep the fertility of the soil up by applying adequate fertilizer or manure with continuous wheat cropping and still continue to produce high yields.
2. By obtaining the data on one or two available plant nutrients of the soil one can not always predict the amounts of phosphorus to be furnished for maximum yields.
3. A high available phosphorus content of the soil does not always guarantee high crop yields. The nitrogen in the soil, either directly or indirectly, may increase the phosphorus uptake by plants and keep the wheat yields high with continuous cropping.
4. Manuring the soil in continuous wheat cropping may keep the yields about as high as complete commercial fertilization if adequate manure is available and it is applied in adequate amounts.
6. One may not always obtain a high correlation between the soil chemical test data and crop yields.

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APPENDIX

TABLE VI

WHEAT GRAIN YIELDS IN BU/A FROM 1930 - 1966

Year	Manure plot	Check plot	P plot	NP plot	NPK plot	NPK + Lime plot
1930	19.1	7.9	7.4	6.5	5.5	5.8
1931	25.0	25.6	25.2	28.4	32.3	32.4
1932	30.2	19.3	23.9	28.6	22.7	27.5
1933	28.0	12.3	22.1	22.9	25.1	23.1
1934	12.7	12.7	18.7	18.0	21.9	12.4
1935	27.7	14.0	24.1	26.1	27.0	28.0
1936	21.8	19.3	19.4	20.2	20.6	16.9
1937	28.3	22.0	28.8	30.3	32.2	32.5
1938	10.2	3.4	11.7	11.7	12.4	14.1
1939	25.2	15.3	25.8	24.4	26.7	28.0
1940	28.2	15.2	28.6	30.6	33.6	33.7
1941	6.4	0.9	8.1	8.7	8.2	8.5
1942	12.5	2.6	10.7	10.9	9.9	10.8
1943	11.3	4.3	9.2	11.9	10.9	12.3
1944	23.3	16.1	24.9	24.1	23.1	23.6
1945	8.1	6.7	6.9	6.1	9.9	10.3
1946	28.4	11.7	12.9	20.9	15.1	12.1
1947	21.2	18.7	20.4	22.4	24.1	20.0
1948	24.9	18.1	33.0	34.4	34.4	33.7
1949	20.9	9.8	15.9	17.4	19.7	20.4
1950	23.4	20.3	24.8	26.4	21.4	26.2
1951	25.9	8.4	18.5	21.4	24.2	29.1
1952	12.0	8.7	15.8	17.1	16.7	29.0
1953	21.6	14.7	24.5	32.0	32.1	33.6
1954	15.0	12.7	15.6	12.5	15.3	16.7
1955	3.3	7.8	8.0	5.4	2.5	6.5
1956	12.3	19.6	19.2	15.1	15.6	15.4
1957	20.8	13.3	15.3	15.8	17.0	14.1
1958	37.5	28.7	24.2	36.9	35.7	37.5
1959	44.5	28.1	27.0	39.5	39.4	43.0
1960	21.9	11.5	29.8	34.0	35.2	33.8
1961	33.6	10.5	17.5	26.1	27.6	29.3
1962	24.6	14.0	18.9	28.5	27.0	30.6
1963	37.9	27.6	22.7	41.5	32.3	44.1
1964	10.1	6.0	17.0	20.7	22.2	23.5
1965	66.4	42.6	42.6	58.0	49.4	54.8
1966	37.1	29.7	25.2	49.0	34.5	38.1
Avg. 1930-1966	23.26	15.10	20.14	23.65	23.33	24.63
Avg. 1947-1966	25.74	17.54	21.80	27.28	26.30	28.92
	+2.48	+2.44	+1.66	+3.63	+2.97	+4.29

TABLE VII

SOIL TEST VALUE DATA OBTAINED FOR THE COMPOSITE SAMPLE OF INDIVIDUAL SUBPLOT IN EACH PLOT (TREATMENT) FOR AVAILABLE PHOSPHORUS, AVAILABLE POTASSIUM AND pH FOR 0" - 6" AND 6" - 12" DEPTH, MAGRUDER PLOTS, 1966

		Soil Test Values					
		0" - 6"			6" - 12"		
Plot	Sub-plot	Available P lbs/A	pH	Available K lbs/A	Available P lbs/A	pH	Available K lbs/A
Manure	1	18.85	5.3	340	22.62	5.3	360
"	2	18.85	5.3	300	15.08	5.2	360
"	3	18.85	5.3	340	22.62	5.4	340
"	4	18.85	5.2	270	11.31	5.2	380
"	5	18.85	5.4	360	11.31	5.4	330
"	6	22.62	5.3	360	22.62	5.5	340
"	7	18.85	5.3	390	11.31	5.2	340
"	8	33.85	5.3	280	11.31	5.4	240
"	9	22.62	5.2	360	18.85	5.2	340
"	10	26.39	5.1	280	22.62	5.1	360
"	11	26.39	5.4	280	30.16	5.6	360
"	12	30.16	5.5	300	30.16	5.5	380
"	13	49.01	5.6	340	26.39	5.4	390
"	14	18.85	5.4	340	15.09	5.4	340
"	15	26.39	5.4	310	22.62	5.4	280
"	16	49.01	5.4	310	30.16	5.5	340
"	17	22.62	5.5	310	18.85	5.6	340
"	18	26.39	5.4	310	15.08	5.4	330
"	19	26.39	5.3	340	33.93	5.4	330
"	20	37.70	5.3	430	30.16	5.3	410
"	21	26.39	5.5	330	26.39	5.5	380
"	22	26.62	5.3	280	22.62	5.4	300
"	23	37.70	5.5	330	18.85	5.5	430
"	24	49.01	5.6	380	49.01	5.7	390
"	25	41.47	5.6	430	30.16	5.6	390
"	26	37.70	5.5	380	30.16	5.7	430
"	27	30.16	5.4	380	33.93	5.6	390
"	28	18.85	5.4	360	33.93	5.5	380
"	29	30.16	5.4	360	30.16	5.4	410
"	30	33.93	5.4	470	30.16	5.4	410
"	31	26.39	5.4	300	45.25	5.7	410
"	32	41.47	5.4	330	33.93	5.5	330
"	33	37.70	5.5	470	30.16	5.4	410
"	34	49.01	5.5	470	37.70	5.7	460
"	35	37.70	5.5	410	49.01	5.8	440

TABLE VII (Continued)

"	36	30.16	5.4	410	33.93	5.5	300
"	37	22.62	5.5	390	37.70	5.6	440
"	38	33.93	5.4	460	41.47	5.7	440
"	39	30.16	5.4	460	33.93	5.6	380
"	40	26.39	5.4	460	22.62	5.5	410
Check	1	41.47	5.4	280	26.39	5.3	180
"	2	45.25	5.3	280	26.39	5.3	150
"	3	41.47	5.3	380	30.16	5.2	300
"	4	37.70	5.3	270	33.93	5.3	360
"	5	26.39	5.4	280	33.93	5.2	210
"	6	22.62	5.4	240	26.39	5.4	210
"	7	30.16	5.4	240	30.16	5.2	220
"	8	41.47	5.3	240	22.62	5.2	300
"	9	33.93	5.4	310	22.62	5.3	360
"	10	30.16	5.3	460	18.85	5.2	460
"	11	18.85	5.5	310	18.85	5.4	310
"	12	18.85	5.5	250	18.85	5.3	380
"	13	22.62	5.4	300	15.08	5.3	350
"	14	15.08	5.4	330	26.39	5.3	300
"	15	15.08	5.3	250	26.39	5.4	330
"	16	18.08	5.4	250	22.62	5.4	310
"	17	11.31	5.5	250	18.85	5.4	300
"	18	15.08	5.5	280	18.85	5.4	300
"	19	15.08	5.3	310	22.62	5.2	270
"	20	18.85	5.4	350	15.08	5.3	340
"	21	18.85	5.4	380	15.08	5.4	300
"	22	15.08	5.4	250	11.31	5.4	360
"	23	18.85	5.4	250	11.31	5.4	360
"	24	15.08	5.3	350	7.54	5.4	390
"	25	18.85	5.4	380	7.54	5.3	390
"	26	7.54	5.3	380	7.54	5.3	390
"	27	7.54	5.4	240	15.08	5.4	340
"	28	7.54	5.4	360	22.62	5.4	270
"	29	11.31	5.3	360	15.08	5.4	340
"	30	11.31	5.3	330	15.08	5.2	340
"	31	7.54	5.3	330	11.31	5.3	300
"	32	7.54	5.3	310	11.31	5.3	250
"	33	7.54	5.3	210	7.54	5.4	250
"	34	15.08	5.2	210	18.85	5.3	250
"	35	15.08	5.2	250	7.54	5.4	250
"	36	15.08	5.4	210	7.54	5.4	340
"	37	7.54	5.4	210	7.54	5.4	340
"	38	18.85	5.5	160	7.54	5.4	340
"	39	18.85	5.4	210	7.54	5.4	360
"	40	15.08	5.4	210	18.85	5.1	360
P	1	74.40	5.3	360	22.62	5.0	270
"	2	74.43	5.3	440	26.39	5.1	270
"	3	67.87	5.3	440	37.70	5.2	330
"	4	37.73	5.3	440	26.39	5.0	330
"	5	52.78	5.3	440	26.39	5.1	330
"	6	41.47	5.3	330	33.93	5.1	200
"	7	71.63	5.3	330	18.85	5.1	200

TABLE VII (Continued)

"	8	41.47	5.3	280	18.85	5.1	150
"	9	26.39	5.3	250	49.01	5.1	210
"	10	75.40	5.2	380	49.01	5.1	280
"	11	33.93	5.4	280	67.87	5.2	280
"	12	30.16	5.3	340	60.32	5.2	300
"	13	26.39	5.5	340	64.09	5.2	310
"	14	30.16	5.3	340	60.32	5.2	310
"	15	41.47	5.4	340	60.32	5.2	310
"	16	64.09	5.3	360	52.87	5.2	300
"	17	56.55	5.2	300	71.63	5.3	220
"	18	67.87	5.2	300	56.55	5.2	210
"	19	98.02	5.3	300	60.32	5.2	210
"	20	75.40	5.1	360	37.70	5.1	270
"	21	101.79	5.3	360	52.87	5.1	270
"	22	82.94	5.2	360	30.16	5.2	270
"	23	116.87	5.3	270	60.32	5.2	240
"	24	79.17	5.3	380	49.01	5.2	330
"	25	79.17	5.2	310	60.32	5.1	280
"	26	98.02	5.2	330	64.09	5.2	250
"	27	86.71	5.2	310	52.87	5.2	220
"	28	86.71	5.2	380	41.47	5.1	220
"	29	60.32	5.2	280	30.16	5.1	280
"	30	64.09	5.2	410	37.70	5.2	210
"	31	101.79	5.2	270	75.25	5.1	220
"	32	86.71	5.1	300	37.70	5.1	220
"	33	113.10	5.3	310	86.71	5.1	220
"	34	82.94	5.2	340	67.87	5.2	220
"	35	94.25	5.2	300	64.09	5.1	210
"	36	98.02	5.1	280	64.09	5.1	240
"	37	79.17	5.2	280	97.17	5.1	240
"	38	52.58	5.2	250	45.25	5.2	250
"	39	75.40	5.2	280	52.87	5.3	340
"	40	64.09	5.2	280	52.87	5.2	360
NP	1	60.32	5.2	410	37.70	5.4	350
"	2	64.09	5.2	330	37.70	5.4	410
"	3	67.87	5.2	360	41.46	5.4	360
"	4	56.55	5.2	440	41.47	5.3	410
"	5	60.32	5.2	380	33.93	5.4	410
"	6	41.47	5.1	380	49.01	5.3	350
"	7	67.87	5.2	300	30.16	5.4	280
"	8	60.32	5.2	410	36.39	5.5	300
"	9	45.24	5.2	330	36.39	5.5	280
"	10	71.63	5.1	380	30.16	5.4	280
"	11	75.40	5.2	410	45.24	5.5	280
"	12	67.87	5.2	410	33.93	5.6	280
"	13	52.78	5.1	390	52.78	5.4	280
"	14	60.32	5.1	430	33.93	5.4	280
"	15	79.17	5.2	430	15.08	5.4	310
"	16	75.40	5.1	430	33.93	5.5	310
"	17	67.87	5.2	350	33.93	5.4	270

TABLE VII (Continued)

"	18	64.09	5.2	380	33.93	5.4	300
"	19	49.01	5.2	350	33.93	5.5	270
"	20	41.47	5.1	350	30.16	5.4	270
"	21	64.09	5.2	350	37.70	5.5	270
"	22	60.32	5.2	410	30.16	5.6	300
"	23	56.55	5.2	410	41.47	5.5	350
"	24	64.09	5.2	410	37.70	5.5	350
"	25	67.87	5.2	430	45.25	5.3	360
"	26	90.48	5.1	430	30.16	5.3	330
"	27	71.63	5.2	310	30.16	5.5	330
"	28	60.32	5.2	350	26.39	5.4	240
"	29	60.32	5.2	330	45.24	5.4	250
"	30	60.32	5.1	330	37.70	5.4	330
"	31	67.87	5.2	360	15.08	5.5	250
"	32	79.17	5.2	360	15.08	5.4	350
"	33	60.32	5.2	330	26.39	5.4	330
"	34	60.32	5.1	380	15.08	5.4	360
"	35	98.02	5.1	380	45.25	5.4	360
"	36	41.47	5.2	310	49.01	5.4	300
"	37	79.17	5.2	310	49.01	5.4	300
"	38	67.87	5.2	330	30.16	5.5	310
"	39	56.55	5.2	310	37.70	5.3	240
"	40	67.87	5.2	310	41.47	5.3	280
NPK	1	49.01	6.2	390	37.70	6.3	460
"	2	45.24	6.5	390	56.55	6.5	460
"	3	75.40	6.4	390	37.70	6.4	460
"	4	56.55	6.2	460	30.16	6.2	460
"	5	56.55	6.1	460	45.25	5.9	460
"	6	37.70	6.0	350	37.70	5.9	460
"	7	49.01	6.1	410	41.47	6.0	410
"	8	52.78	5.9	410	41.47	5.9	410
"	9	64.09	5.8	380	37.70	5.5	330
"	10	86.71	5.6	380	41.47	5.6	410
"	11	52.78	6.1	380	49.01	6.0	480
"	12	45.24	6.3	460	30.16	6.2	430
"	13	56.55	6.1	480	26.39	6.1	430
"	14	52.78	6.0	480	41.47	6.0	520
"	15	56.55	5.7	480	56.55	5.6	440
"	16	56.55	5.9	480	30.16	5.9	490
"	17	52.78	5.9	480	30.16	5.7	250
"	18	52.78	5.7	510	22.62	5.7	250
"	19	49.01	5.5	430	41.47	5.6	200
"	20	79.17	5.5	520	33.93	5.6	366
"	21	71.63	5.7	460	41.47	5.8	390
"	22	45.25	5.9	580	41.47	5.9	330
"	23	45.25	5.7	490	33.93	5.8	410
"	24	63.32	5.6	490	45.24	5.6	430
"	25	56.55	5.5	460	37.70	5.6	350
"	26	56.55	5.5	410	30.16	5.6	350
"	27	41.74	5.4	410	30.16	5.4	350

TABLE VII (Continued)

"	28	49.01	5.4	350	37.70	5.4	440
"	29	52.78	5.3	380	30.16	5.3	350
"	30	41.47	5.3	510	30.16	5.4	350
"	31	45.24	5.4	380	41.46	5.5	270
"	32	52.78	5.4	490	26.39	5.5	390
"	33	49.01	5.3	540	37.70	5.5	390
"	34	67.86	5.3	540	37.70	5.5	390
"	35	60.32	5.2	540	37.70	5.4	300
"	36	56.55	5.2	540	33.93	5.4	300
"	37	52.78	5.1	490	37.70	5.3	390
"	38	67.87	5.1	330	30.16	5.3	280
"	39	52.78	5.1	430	41.47	5.3	350
"	40	56.55	5.1	430	49.01	5.2	350
NPK + Lime	1	41.47	5.6	410	18.85	5.8	360
"	2	26.39	5.6	330	22.62	6.1	330
"	3	33.93	5.9	330	22.62	6.1	330
"	4	33.93	5.7	310	26.39	6.0	360
"	5	29.39	5.8	410	26.39	6.0	350
"	6	49.01	5.9	350	30.16	6.4	300
"	7	52.78	6.0	460	26.39	6.2	360
"	8	33.93	6.0	310	30.16	6.1	350
"	9	33.93	5.9	350	26.39	5.9	350
"	10	37.70	5.4	440	30.16	5.7	330
"	11	22.62	6.0	410	30.16	6.2	390
"	12	60.32	6.2	410	15.08	6.4	460
"	13	49.01	6.1	380	30.16	6.3	360
"	14	37.70	6.3	440	30.16	6.3	360
"	15	37.70	6.2	440	7.54	6.4	360
"	16	52.78	6.3	380	11.31	6.5	360
"	17	41.47	6.5	330	41.47	6.6	280
"	18	26.39	6.3	330	30.16	6.5	380
"	19	60.32	5.9	390	41.47	6.3	300
"	20	22.62	5.6	360	37.70	6.0	350
"	21	18.85	6.4	360	33.93	6.5	300
"	22	26.39	6.2	360	30.16	6.6	360
"	23	49.01	6.4	330	18.85	6.5	350
"	24	37.70	6.4	390	22.62	6.6	360
"	25	33.93	6.4	390	30.16	6.7	380
"	26	67.87	6.4	360	30.16	6.7	300
"	27	41.47	6.5	410	49.01	6.6	410
"	28	67.86	6.3	410	26.39	6.5	310
"	29	45.24	6.2	460	22.62	6.4	330
"	30	56.55	5.9	480	30.16	6.1	380
"	31	67.87	6.6	430	26.39	6.6	390
"	32	64.00	6.6	460	18.85	6.8	350
"	33	60.32	6.5	360	33.93	6.7	350
"	34	60.32	6.6	360	45.24	6.7	360
"	35	52.78	6.5	360	30.16	6.6	300
"	36	64.09	6.5	410	41.47	6.7	360

TABLE VII (Continued)

"	37	71.63	6.6	360	45.24	6.6	330
"	38	64.09	6.2	440	52.78	6.7	330
"	39	75.40	6.4	460	45.24	6.5	330
"	40	71.63	6.0	480	56.55	6.0	410

TABLE VIII

ANALYSIS OF VARIANCE OF pH VALUE VARIATION ON THE WHOLE LAYOUT, MAGRUDER PLOTS, 1966

Source	d.f.	M. S.	Calc. F.
Treatments (Plots)	5	12.478	819.23**
Depth	1	0.545	35.76**
Blocks (Across)	9	0.226	14.85**
Column (Along	3	0.137	9.03**
Treatment X Depth	5	0.385	25.25**
Treatment X Column	15	0.750	49.24**
Residual	441	0.015	

TABLE IX

ANALYSIS OF VARIANCE OF AVAILABLE POTASSIUM DISTRIBUTION ON THE WHOLE LAYOUT, MAGRUDER PLOTS, 1966

Source	d.f.	M. S.	Calc. F.
Treatments (Plots	5	176135.527	70.35**
Depth	1	126425.208	12.64**
Blocks	9	14698.045	5.87**
Columns	3	4986.142	1.99N.S.
Treatment X Depth	5	34268.088	13.69**
Treatment X Columns	15	11010.502	3.39**
Residual	441		

N.S. Not significant
** Significant at the 1% level

TABLE X

THE CORRELATION COEFFICIENTS BETWEEN SOIL TEST VALUES FOR PHOSPHORUS, POTASSIUM AND pH AT THE TWO DEPTHS AND 20 YEARS AVERAGE YIELD OF WHEAT GRAIN, MAGRUDER PLOTS, 1966

Variables Correlated	Correlation Coefficient Values
P at 0" - 6" X pH at 0" - 6"	-0.119
P at 0" - 6" X K at 0" - 6"	0.409
P at 0" - 6" X P at 6" - 12"	0.915
P at 0" - 6" X pH at 6" - 12"	-0.053
P at 0" - 6" X K at 6" - 12"	-0.369
P at 0" - 6" X Yield	0.416
pH at 0" - 6" X K at 0" - 6"	0.500
pH at 0" - 6" X P at 6" - 12"	-0.148
ph at 0" - 6" X ph at 6" - 12"	0.953
ph at 0" - 6" X K at 6" - 12"	0.529
pH at 0" - 6" X Yield	0.501
K at 0" - 6" X P at 6" - 12"	0.316
K at 0" - 6" X pH at 6" - 12"	0.563
K at 0" - 6" X K at 6" - 12"	0.688
K at 0" - 6" X Yield	0.798
P at 6" - 12" X pH at 6" - 12"	-0.184
P at 6" - 12" X K at 6" - 12"	-0.399
P at 6" - 12" X Yield	0.243
pH at 6" - 12" X K at 6" - 12"	0.567
pH at 6" - 12" X Yield	0.680
K at 6" - 12" X Yield	0.524

TABLE XI

SOIL PROPERTIES OF THE MAGRUDER PLOTS

The surface soil contains 46% sand, 38% silt and 16% clay (23). The slope is 1 to 2% south faced.

The soil was classified as Kirkland silt loam (45) that is defined as having a grayish-brown color from 6 to 10 inches depth over a dark grayish-brown, blocky, compact claypan becoming browner below 24 inches. Many $CaCO_3$ concretions occur in the lower part. The subsoil is very slowly permeable. Substrata are composed of silty clays and silty clay loams.

The profile described is about 600 feet west of the Magruder Plots (45).

Profile:

A_{1p}	0-8"	Grayish brown (10 YR 4.5/2; 3.5/2 when moist) heavy silt weak medium granular; friable, permeable, pH 6.5; a few fine pores; rests abruptly on the layer below.
B_{2-1}	8-22"	Dark grayish-brown (9 YR 4/2; 3/2 when moist) clay; moderate fine blocky; very firm; sticky and plastic when wet; very slowly permeable; pH 7.0; sides of peds are varnished and have strong clay films; occasional fine black concretions; grades through a 4 inch transition to a layer below.
B_{2-2}	22-32"	Dark grayish brown (10 YR 4/2; 3/2 when moist) clay; weak angular blocky; very firm and compact; very slowly permeable; pH 7.5; occasional fine black pellets, a few strong brown specks about the tiny root holes; many fine $CaCO_3$ concretions below 24 or 26 inches; peds have a weak shine when moist; grades through a 3 inch transition to the layer below.
B_3	32-42"	Brown (7.5 YR 5/4; 4/3 when moist) light clay; weak medium blocky; firm or very firm; very hard when dry; pH 7.5; occasional black pellets and $CaCO_3$ concretions;

		sides of peds have weak coatings of dark brown (7.5 YR 4/2 when moist); grades to the layer below.
C_1	42-52"	Reddish-brown (5 YR 5/4; 4/4 when moist) heavy silty clay loam or light silty clay, much like the layer above; pH 7.5; occasional large $CaCO_3$ concretions and black ferruginous films; grades to the layer below.
C_2	52-64"	Reddish-brown (3.5 YR 5/4; 4/4 when moist) silty clay loam, splotched with 10% of red (2.5 YR 4/6) has occasional light gray streaks; weak irregular blocky; firm; slowly permeable; pH 7.5; occasional fine black pellets and fine concretions of $CaCO_3$; grades to the layer below.
C_3	64-84"	Red (2.5 YR 4/6; 3/6 when moist) silty clay, with occasional light gray streaks and splotches; weak medium blocky; firm but not compact; pH 7.5; many fine pores; changes little to greatest depth sampled.

VITA

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