

DETERMINING THE PHOSPHORUS FERTILIZER
NEEDS FOR SOILS OF THE HIGH
PLAINS IN OKLAHOMA

By

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CHAPTER I

INTRODUCTION

The soils of the High Plains in the Oklahoma Panhandle are generally well supplied with available phosphorus, and responses to added phosphorus have been infrequent in numerous experimental tests on both sorghum and wheat. However, occasionally low available P is reported from soil tests submitted to testing laboratories, and increased growth and yields from applied P fertilizer to these soils have been reported by farmers. In addition, some growers and fertilizer dealers have reported increased yields from added P fertilizer even when soil test values were high.

The extractant used for available P varies between soil testing laboratories, and some test results are being reported where the extractant used is not particularly adapted to the high calcium soils of the area. Sodium bicarbonate and a wide soil-solution ratio of the Bray-I extractant generally appear to be the most satisfactory extractants for available P for calcareous soils of the High Plains region (42). However, data from field tests are still rather limited, as no concerted effort has previously been made to calibrate soil tests specifically for the alkaline soils of the Oklahoma Panhandle.

The objectives of this research were: 1) to determine the reliability of predicting responses of winter wheat (*Triticum aestivum* L. em. Thell.) and grain sorghum [*Sorghum bicolor* (L.) Moench] to P fertilizer

in the High Plains of Oklahoma and 2) to study the P status of selected soils of the High Plains soil resource area of Oklahoma.

CHAPTER II

REVIEW OF LITERATURE

Phosphorus is a major nutrient occurring in most plants in quantities that are much smaller than those of nitrogen and potassium. It is present in all living tissue, and it is particularly concentrated in the younger parts of the plant and in the flower and seed. Some of the many functions of P within plants are as follows: stimulates early root formation and growth, gives rapid and vigorous start to plants, hastens maturity of crops, especially important in seed formation, and increases the ratio of grain to stalk. With the possible exception of nitrogen, no other element has been as critical to the growth of plants in the field as has P.

The total P content varies from soil to soil, but it is generally higher in young virgin soils. It ranges from less than 100 to 4,000 lbs. an acre and averages about 1,000 lbs. (33). Total supply of P in many soils might be adequate to take care of crop needs for many years, but a large portion of phosphorus in the soil may not be available. Different forms of P vary in their availability to plants. Buckman and Brady (8) stated that, at any one time, perhaps 80-90 percent of the soil phosphorus is in "very slowly available" forms. Most of the remainder is in the slowly available form, since perhaps less than one percent would be expected to be readily available. In spite of the conversion, a major portion of the added P to less available forms, it

should be remembered that the reverted P is not lost from the soil and through the years undoubtedly is slowly available to growing plants. This becomes an important factor, especially in soils which have been heavily phosphated for years.

Forms of Soil Phosphorus

Olsen (33) stated that P occurs naturally in soils in the form of the calcium phosphates, iron phosphate, aluminum phosphate, various primary and secondary minerals in which a phosphate group is in a crystal lattice, and as organic phosphorus which may constitute as much as 75 percent or as little as 3 percent of the total soil P.

Chai and Caldwell (9) found more of the total soil P in the aluminum and iron fractions in acid soils and more of the total soil P in the calcium fraction in calcareous soils.

Phosphorus Fixation and Its Mechanism

It has long been recognized that P added to the soil soon becomes fixed or immobilized. This phenomenon has been of considerable interest since the extent to which a particular soil will fix added P will determine the efficiency and economics of fertilizer use on the soil.

Wild (56) states that "P fixation is used to describe any change that P undergoes in contact with soil, which reduces the amount that the plant roots can absorb." According to Olsen (33), P fixation is the process of changing soluble P into less soluble P in soils. Tisdale and Nelson (48) defined fixation of P as a reduction in the solubility of P added.

Phosphorus fixation in the soil is dependent on pH value, content

of clay, and nature and amount of exchangeable cations present in the exchange complex (49). Bear (5) indicated that the fixation of P was due to the result of a reaction between free oxides of iron or aluminum or formation of insoluble salts of iron and aluminum or calcium as well as fixation by clay minerals.

Coleman et al. (15) reported a significant correlation between absorbed P and the exchangeable aluminum content of the soil. They also stated that removal of exchangeable aluminum reduced P absorption. More recently, Yuan and Breland (59) found active aluminum to correlate better than iron with the retention of added P. Likewise, Bromfield (7) concluded that P absorption was due mainly to active aluminum, with iron having only a minor role in acid soils.

Hsu and Rennie (21) found initial fixation of P by Al hydroxide to be primarily an absorption reaction. The initial fixation was thought to be followed by a slower decomposition-precipitation process. Hsu (20) believes absorption to be a special case of precipitation. Al or Fe remains as the constituent of the original phase but reacts with P due to residual forces on the surfaces. Thus, it is the surface-reactive amorphous Al or Fe oxides and not Al^{+3} or Fe^{+3} that are the real factors governing the concentration of P in solution. While the activities of Al^{+3} or Fe^{+3} are negligible at pH5 or above, there is no such limitation imposed on the surface activities of amorphous Al or Fe compounds. Hsu found no crystallization of Al-P from amorphous compounds in six months and suggested that such crystallization may never take place since surface reactive amorphous compounds are continuously added to the system through the weathering process. Similarly, Chang

and Chu (10) indicate that it is the surface areas and not the amount or activity of the Al or Fe present that determines P fixation.

There is also considerable evidence for the existence of variscite-strengite compounds in soils. Haseman, Brown, and Whitt (18) performed experiments on clay minerals and observed an initial rapid reaction due to the reaction of P with readily available Al and Fe, and a subsequent slower reaction involving Al and Fe released during the decomposition of these minerals. They suggested that P might be fixed in the soil as substituted palmerites and as compounds in the variscite-barrandite-strengite isomorphous series. Wright and Peech (58) also found some crystalline P minerals of the variscite-strengite isomorphous series to be the ultimate reaction product in acid soils. Coleman, Thorup, and Jackson (15) observed a correlation between phosphorus absorption and exchangeable Al and suggested the formation of a variscite-like compound.

Lindsay et al. (26) stated that the pK_{sp} value of highly purified synthetic variscite, $Al(OH)_2H_2PO_4$, was found to be 30.5 at 25° C and the equilibrium between variscite and its constituent ions in solution was attained only very slowly. The solubility criteria indicated that the immediate reaction products of P applied to acid soils are much more soluble than variscite, but upon aging these intermediate reaction products are slowly transformed into variscite which may exist with gibbsite as a stable solid P.

Phosphorus fixation in alkaline and calcareous soils is usually attributed to the formation of P compounds of calcium. In addition, however, the iron and aluminum compounds responsible for fixation in acid soils are also responsible for some fixation in soils of higher pH.

Russell (39) stated that the calcium ions which hold P in a soil may be calcium ions in solution, exchangeable calcium ions forming calcium phosphates on the surface of the clay particles, or calcium ions anchored on the surface of calcium carbonate crystals.

Midgley (29) believed that P in calcareous soils seems to be fixed as a carbonate-phosphate complex rather than simple tricalcium phosphate. McGeorge (28) stated that Arizona soils have a strong fixing power for soluble P because of solid-phase calcium carbonate and high pH.

Cole et al. (14) studied the absorption of P on calcium carbonate and suggested that when soluble P fertilizers are added to calcareous soils, the reactions with calcium carbonate consisted of rapid monolayer absorption on calcium carbonate surfaces.

Tisdale and Nelson (48) concluded that the activity of P in alkaline or calcareous soils is largely governed by 1) Ca^{+2} activity, 2) the amount and particle size of free calcium carbonate in the soil, and 3) the amount of clay present. The activity of the P will be lower in those soils that have a high Ca^{+2} activity, a large amount of finely divided calcium carbonate, and a large amount of calcium-saturated clay.

Perkins (35) studied the effect of various mixtures of cations with P on P precipitation through a range of pH values from 2.5 to 9.5 and concluded that increasing cationic concentrations increased P precipitation whether single or mixed cations were used. As the pH increased from 2.5 to 9.5, phosphate fixation by calcium steadily increased. At acid reactions, calcium phosphate precipitated slightly more P than magnesium, but much more than magnesium at basic reactions.

In general, the more complex the cationic solution with total cation concentration remaining constant, the lower the P precipitation.

Rennie et al. (38) concluded that the calcium ion will not precipitate P from solution if the pH is sufficiently low. They obtained no significant precipitation of calcium phosphate until the pH approached 5.5 and maximum precipitation did not occur until the pH approached 7.6. The precipitation of iron and aluminum phosphates was negligible at pH5.

Low and Black (27) accounted for the fixation of P by kaolinite by hypothesis that kaolinite dissociates into aluminum and silicate ions and that P precipitates the aluminum ion, thereby disturbing the equilibrium and causing the clay to dissolve in accordance with solubility product principles. A similar observation was made by Kittrick and Jackson (22) and by Tamimi et al. (44). Likewise, Hemwall (19) postulated that P was fixed by clay minerals by reacting with soluble aluminum, which originated from the exchange sites or from lattice dissociation of the clay minerals, to form a highly insoluble Al-P compound. The reactions followed the solubility product principle and resulted in the formation of variscite. The rate of fixation of P was found to be dependent upon the rate the clay replenished the solution with soluble aluminum; with lattice dissociated aluminum, the reaction was slow, while with exchangeable aluminum, the reaction was rapid.

Haseman et al. (18) stated that the rate of P fixation by montmorillonite, illite, and kaolinite clay increased with a rise in temperature, increased concentration of P and a lowering in pH. The rate of fixation by hydrous oxides, gibbsite, and goethite increased with a rise in temperature, but was affected little by variation in pH in the

0.1M phosphate solution. The decreasing order in which the soil minerals fixed P was: gibbsite, goethite, kaolinite, and montmorillonite.

Fractionation of Soil Phosphorus

Fractionation of inorganic phosphorus in the soil has recently received extensive study in soil fertility. The only important difference between the different methods of fractionation lies in the type and concentration of extraction solutions.

Phosphorus fractionation procedures were greatly improved in 1957 when Chang and Jackson (11) reported on their systematic method of P fractionation by which it was possible to fractionate soil inorganic P into discrete chemical forms as follows:

1. Aluminum phosphate extracted with neutral 0.5 N NH_4F
2. Iron phosphate extracted with 0.1 N NaOH
3. Calcium phosphate extracted with 0.5 N H_2SO_4
4. Reductant soluble iron phosphate extracted with a basic dithionite citrate solution
5. Occluded aluminum phosphate extracted with neutral 0.5 N NH_4F after the dithionite treatment

There are some objections and criticisms on this procedure. The most severe criticism has been the apparent inability of NH_4F to accurately assess the Al-P fraction in fertilized soils. Chang and Jackson (11) found the measurement to be fairly distinct in unfertilized soils. Even so, they admitted that NH_4F could dissolve some Fe-P and recommended subtracting 10 percent of the Al-P fraction and adding it to the Fe-P fraction.

Fife (16) believed that P released from aluminum compounds by NH_4F

could be resorbed onto iron compounds causing underestimation of Al-P and subsequent overestimation of Fe-P. He recommended eliminating such absorption by raising the pH of the NH_4F extractant to 8.5.

In calcareous soils Al-P and Fe-P may be underestimated. According to Williams et al. (57) the carbonate ion in CaCO_3 may be replaced by the fluoride ion during extraction with NH_4F . The resulting CaF_2 can absorb P causing underestimation of Al-P and Fe-P.

Determining Phosphorus Needs for Crop Production

An accurate method for determining fertilizer needs has been a subject receiving considerable attention for many years. Bray (6) reviewed the historical development of these efforts and noted that, in general, three methods have been followed: 1) field trials, 2) pot cultures, and 3) chemical studies of the soil and elemental uptake by plants growing on the soil. All three methods have proven useful, but modern farming requires that the method must be rapid and relatively inexpensive as well as accurate. For this reason, suitable chemical tests on both soil and plants have received wide attention.

Soil Tests

Early studies involved total analysis of the soil, but these would not correlate with field responses. It is now recognized that only a fraction of the P in soils is available for direct use of growing plants, and as noted from the previous section of this thesis, the form of P in the soil is an important factor in availability of P for plant growth.

According to Olsen et al. (32), a soil test which successfully

determines the available phosphorus in a soil must fulfill the following requirements:

- (1) It must extract all or a definite proportion of the various forms of soil P in the same relative amounts as they are absorbed by plants.
- (2) It must measure with reasonable accuracy the amount of P in the extract.
- (3) It must correlate fairly closely with the amount of P taken up by plants and the yield responses to added P over a wide range of soils.
- (4) It must minimize secondary precipitation and absorption reactions which may occur during the reaction.
- (5) It must be fairly rapid in its action.

Several methods have been devised for the measurement of the available P fraction. One of the earliest was that of Truog (50) in which the available P is extracted from soil with 0.002 N sulfuric acid buffered with ammonium sulfate at a pH of 3. This was followed by the method of Morgan (30) in which the extracting solution is 10 percent sodium acetate.

McGeorge (28) suggested a carbonic acid extraction for alkaline Arizona soils, because this acid is weak and is similar to the mechanism he believed was operative at plant root surfaces.

Bray and Kurtz (6) later introduced their No. 1 and No. 2 methods. The extraction solution in the No. 1 method was made up of 0.03 N ammonium fluoride and 0.025 N hydrochloric acid, while in the No. 2 method, the concentration of ammonium fluoride remained the same as No. 1, but the concentration of hydrochloric acid was increased to 0.1 N. They also stated that their methods will need to be modified if appreciable amounts of arsenic or quantities of iron much over 15 ppm. are extracted.

Olsen et al. (32) developed a method in which the extraction solution was 0.5 M sodium bicarbonate and applicable for most calcareous or alkaline soils.

Saunders (40) introduced a method in which the extracting solution was hot 0.1N sodium hydroxide for extracting available P from tropical soils, particularly red soils, where P was present in strongly absorbed forms.

Different merits and demerits have been claimed for each of the above methods of determination of available P, but a particular method becomes useful only when the results obtained with it can be correlated with crop responses to fertilizer in the field for the particular area concerned.

Pratt and Garber (36) and Chai and Caldwell (9) have made a comparison of some of these methods. They concluded that the relative distribution of available P as determined by NaHCO_3 was different from Bray No. 1 and Bray No. 2 methods, and also the total amount extracted was lower. The Bray No. 2 method, which is a more acidic solution than Bray No. 1, extracted more P from alkaline soils but decreased amounts from the acidic soils. The 1 percent citric acid solution gave a relative distribution similar to the Bray No. 1. The Morgan method extracted much less P than the other methods.

Weir (55) evaluated some of the above methods on some Jamaican soils. According to him, in the order of decreasing precision of estimating the available P of the soils, the methods are as follows:

- 1) 0.002 N sulfuric acid method by Truog,
- 2) 0.1N HCL method by Bray,
- 3) 0.5 M NaHCO_3 method of Olsen,
- 4) 10 percent sodium acetate method of Morgan,
- and 5) 0.1N NaOH method of Saunders.

Peck, Kurtz, and Tandon (34) studied the changes in Bray No. 1 soil P test values resulting from additions of fertilizer in both laboratory and field conditions. They found that Bray No. 1 values for P increased approximately 1 pp2m for each 4 pp2m of P added in fertilizer in field experiments over a period of years. Under laboratory conditions with a period of 49 weeks, additions ranging from 2 to 10 pp2m of P were required to increase the soil test by 1 pp2m.

Some workers have based the availability of the various P forms on results obtained by the Chang and Jackson procedures.

Susuki, Lawton, and Doll (43) studied on Michigan soils, and they concluded that P removed by cropping was derived from Ca-P and Al-P.

Al-Abbas and Barber (1), using multiple regression analysis, found Fe-P produced the best correlation with P uptake by the plants. However, Halstead (17) concluded that Al-P gave the best relation with both percent yield and percent P uptake on some Canadian soils.

Alexander and Robertson (2) reported Al-P and Fe-P forms to be the major sources of available P in some Alberta soils of Canada.

Norwood (31) studied some important soil series of Oklahoma and stated that Al-P was found to be a main source of P in all soils; Fe-P was utilized to a much lesser extent. The status of Ca-P was found to be in doubt.

While most workers agree that certain forms of Al-P and Fe-P are available to plants, there is a difference of opinion as to the availability of Ca-P. Chu and Chang (13) stated that due to their greater amount of surface-P and specific surface activity, Al-P and Fe-P may be more important as a source of P. The low specific surface activity of Ca-P may keep it from being the main source of P even in calcareous

soils. On the other hand, Chang and Jackson (12) stated that Ca-P was more available to plants than other forms of P. They said Ca-P was more soluble than other P forms and thus more easily removed by crops.

Shelton and Coleman (41) found that the degree of saturation of P fixation capacity necessary for maintaining high available P levels depends upon the relative proportions of Al-P and Fe-P and the rate of conversion of Al-P to Fe-P. Saturation of the P fixation capacity was more efficient in soils that fixed a large amount of applied P as Al-P.

Several workers have applied specific P compounds to soils and studied crop responses. Taylor, Carney, and Lindsay (45) found calcium ferric phosphate, potassium taranakite, colloidal Al-P and colloidal Fe-P to be relatively good sources of P, and stated that forms of P could not be responsible for the "fixation" of P from water soluble fertilizers. Lindsay and DeMent (25) found colloidal Fe-P to be partially available to plants. Colloidal Fe-P increased in availability during the cropping period, probably because of enlargement of the soil-fertilizer reaction zone. Strengite gave no response on acid soils and was only slightly available on alkaline soils. Later, Taylor et al. (46) found amorphous Al-P to be a moderately effective source of P on acid soils. Crystalline variscite was ineffective. On calcareous soils they found Al-P, variscite, and potassium and ammonium taranakites to be as effective as monocalcium phosphates. Puente (37) summarized wheat fertilizer experiments in Oklahoma and obtained good correlations between Bray No. 1 and NaHCO_3 extractable P with increased yields to applied P.

Plant Analyses

Tissue analyses concerned with diagnosis of the nutritional status of crops as an index of the amounts of available nutrients present in the soil have proved to be a valuable tool in supplementing many soil tests for determining "available" soil P. The results are quantitative and precise, but translating the analytical results into meaningful interpretation is very difficult.

Ulrich (51) stated that the concentration of a nutrient in the plant as a whole or in part of it is a function of soil, climate, plant, time, management, and possibly other factors.

Thomas (47) indicated that the leaf may serve as an index tissue in the integration of all factors that influence the availability of soil nutrients and their uptake by plants. Thomas further states the time to take leaves for diagnosing available nutrients is at flowering time when the vegetative parts of the plant are fully grown but still vigorous. He also pointed out that the uptake of an element is not always in direct proportion to external concentrations, a fact which accounts for the difficulties encountered in the method of traditional agronomy in seeking too closely for a direct relationship between applied fertilizer and yield.

Viets and Hanway (52) stated that the chemical composition of plants varies according to the supply of nutrients available for their growth. The percentage of a nutrient in the plant generally increases as nutrient availability is increased. Because plants growing in the field reflect the effect of all factors that have influenced nutrient availability to the plant, an analysis of the plant may provide information not obtained by analysis of soil samples. Plant analysis is

particularly useful in detecting mild deficiencies before they become acute and deficiency symptoms appear.

Baker (3) reported that progress in establishing critical levels of nutrients in different crops has been limited by the fact that the concentration in the plants changes very rapidly with the stage of growth. Often alterations in nutrient concentrations due to change of growth are greater than differences caused by the amount of available nutrient in the soil. Therefore, it is necessary that a critical level be established for each growth stage or that samples be collected at a specific, pre-determined stage of growth. Concentration of elements differs with plant parts also. For instance, leaves will contain different concentrations than stems. Also, leaves at the top of the plant will be different from those at the lower part of the plant.

Lane and Walker (23) studied the mineral accumulation and distribution in grain sorghum throughout the growth cycle in response to N, P, and K application. They found that a faster rate of growth and the production of plants of larger size and dry weight resulted from application of N and P. They also concluded that accumulation of nutrients in sorghum seems to fit the general pattern in other plants. Sorghum may take up nutrients over a longer period of the growth cycle than some cereals. The distribution of these nutrients within the plant was little affected by the supply of N. Both N and P moved out of the leaves to the developing head, resulting in early aging of leaves, except the supply was quite high.

Ward and Carson (54) applied five treatment combinations of N, P, and K to wheat, barley, and oats. The top three leaves were analyzed and the main differences in leaf nutrient levels were 1) higher K

concentration in oat leaves, 2) higher Ca concentration in barley leaves, and 3) higher N and P concentration in wheat leaves. Critical concentrations were: wheat 3.60% N, .26% P, 1.60% K, .20% Ca; barley 3.20% N, .23% P, 1.60% K, .50% Ca; oats 3.00% N, .23% P, 2.00% K, .20% Ca. Baker (4), working on winter wheat, found the critical level for 15 and 27 March was 350 ppm nitrate nitrogen or 4.5 percent organic nitrogen. The concentration of P was the most consistent of all nutrients since concentration was not a function of stage of growth. The critical level was 0.45 percent for all growth stages. The critical level of potassium was the most difficult to establish since the effect of date of sampling was very large. The critical concentration of potassium was 3.0 percent on 1 December, 2.2 percent on 17 January, 2.5 percent on 15 March, and 3.0 percent on 27 March.

CHAPTER III

MATERIALS AND METHODS

Field Experiment

Twenty sites were selected for the grain sorghum tests in 1972 and 25 sites for the wheat tests during the 1972-1973 wheat season.

Sites were selected which represent the important irrigated sorghum and wheat soils of Northwest Oklahoma. Consideration in site selection included:

1. Kind of soil and acreage of the soil devoted to irrigated grain sorghum and wheat.
2. Soil test "P" values. Attempts were made to choose locations testing from low to very high in available P.
3. Management attributes of the grower. Cooperators were selected who were known to carry out good management practices.
4. Consideration was given to spacing the studies across the area as much as feasible.

Of the 20 experimental locations in the grain sorghum tests, 17 were harvested. Three sites were lost for various reasons. Two of the wheat studies were not harvested.

Soil Characteristics

Prior to the fertilizer applications, soil samples were taken from the "0" to "6" inch layer from each location. These samples were taken

to the laboratory and dried and prepared for the different soil analyses.

Results of the physical and chemical analysis of the soil are given in Table I and Table II.

Treatments Used in the Field Experiment

A randomized block design with four replications and six treatments was used. Each plot was 80 feet long and 14 feet wide in the grain sorghum tests, and 100 feet long and 14 feet wide in the wheat tests. Levels of P added were 0, 20, 40, 60, 80, and 100 lbs. P_2O_5/A . In general, the farmers applied sufficient nitrogen as anhydrous ammonia in the sorghum tests, but wet soils during the nitrogen topdressing season for wheat resulted in a nitrogen deficiency at several of the wheat sites. The P was applied broadcast for the wheat and banded in the bed for grain sorghum. The source of P was concentrated superphosphate (0-46-0).

The grain sorghum tests were harvested by hand. Thirteen and one tenth feet of two rows (40") were harvested from each plot.

In the wheat tests, an area of 84 feet by 8 feet was harvested by combine.

Laboratory Experiment

Available Soil P Extraction Procedures

After harvesting the grain sorghum tests, representative soil samples were taken from five selected locations with varying soil properties. Two locations in which large yield increases and three locations giving little or no response to the P applications were chosen.

TABLE I
SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS
USED IN GRAIN SORGHUM FIELD TESTS

Test #	Location	Soil Type	pH	lbs./A		
				NO ₃	P	K
1	Texas Co.	Richfield clay loam	7.3	150	70	800
2	" "	" " "	7.4	160	29	1105
3	" "	" " "	8.0	15	24	670
4	" "	" " "	7.4	110	44	765
6	" "	" " "	7.8	360	36	1220
7	" "	" " "	7.7	40	173	1510
8	" "	" " "	7.0	140	39	930
11	Cimarron Co.	" " "	6.9	74	27	650
12	" "	Mansker Dalhart loam	8.0	33	39	630
13	" "	Richfield clay loam	7.8	90	182	1250
14	" "	" " "	7.9	13	58	580
15	Beaver Co.	Mansker clay loam	8.0	10	10	665
16	" "	Richfield clay loam	6.9	100	56	790
17*	" "	Dalhart fine sandy loam	6.4	21	15	405
18	" "	" " "	7.6	12	63	600
19	" "	" " "	7.5	35	87	575
20	" "	Richfield clay loam	6.8	74	43	445

*Dry land

TABLE II
SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS
USED IN THE WHEAT FIELD TESTS

Test #	Location	Soil Type	pH	NO ₃	P	K
				lbs./A		
1	Texas Co.	Richfield clay loam	7.8	21	10	810
2	" "	" " "	7.8	97	22	753
3	" "	Mansker potter complex	7.7	35	29	937
4	" "	Ulysses	8.0	23	29	845
5	" "	Richfield clay loam	7.5	27	20	837
6	" "	" " "	6.8	10	80	851
8	Cimarron Co.	" " "	7.2	28	65	959
9	" "	Richfield fine sandy loam	7.1	21	60	837
10	" "	Richfield clay loam	7.8	89	41	660
11	Texas Co.	" " "	7.3	60	20	1009
12	Beaver Co.	Richfield loam	7.7	13	38	684
14	" "	Dalhart fine sandy loam	7.0	94	40	586
15	" "	" " " "	6.8	16	28	610
16	" "	Ulysses Richfield complex	6.9	60	113	1555
17	" "	Richfield clay loam	7.3	30	21	839
18	Texas Co.	" " "	7.9	83	10	1255
19	" "	" " "	7.6	30	30	938
20*	Harper Co.	Carey silt loam	7.8	14	11	473
21*	" "	St. Paul silt loam	7.0	41	21	705
22*	" "	Carey silt loam	7.9	40	22	521
23*	Ellis Co.	Pratt loamy fine sand	7.6	26	15	519
24*	" "	Richfield clay loam	6.7	14	38	485
25*	" "	Mansker-Otto F.S.L.	7.9	34	26	525

*Dry land

In these soil samples, the following methods of extracting available P were used:

1. 0.5 M sodium bicarbonate adjusted to a pH value of 8.5 with a 1:20 soil-solution ratio (32).
2. Bray No. 1 method: 0.025 N HCl + 0.03 N NH₄F with two soil-solution ratios of 1:20 and 1:50 (6).

Successive Extraction of Available Soil P

The five soil samples were successively extracted 8 times by using Bray No. 1 method with 1:20 soil-solution ratio to study the replenishing power of available P of the soils.

The following method was used:

1. Place 5 g. soil sample + 100 ml Bray No. 1 extracting solution in a 250 ml volume centrifuge tube.
2. Shake for 5 minutes on a mechanical shaker.
3. Centrifuge for 10 minutes at 3,000 RPM.
4. Filter and save the supernatant for P determination. Keep the soil in the centrifuge tube.
5. Repeat this procedure for 8 times on the same soil sample.

Recovery of Applied Water Soluble P

Solutions of monocalcium phosphate [Ca(H₂PO₄)₂H₂O] were prepared and mixed with the soils so that each soil sample received 0, 20, 40, 60, 80, 100, 150, and 200 lbs. P₂O₅/A. After six weeks of incubation, the samples were dried, crushed, and mixed again. Phosphorus was determined by the Bray No. 1 (1:20 soil-solution ratio) extraction procedure.

Plant Analyses

When the grain sorghum plants were one to two feet tall, two locations (Test 1 and Test 6) were visually chosen from the seventeen different locations according to their differences in growth with regard to the rate of P applied.

Five representative plants were collected from each plot at three different growth stages. These were:

Growth stage 1 -- Plants were 1-2 feet tall

Growth stage 2 -- Early bloom

Growth stage 3 -- Harvesting time

The plants were brought to the laboratory where the diameter of stems were measured and the plants were separated into leaves and stems. The fractions were thoroughly dried in an oven at 150° F and were weighed and then ground on a micro-wiley mill. A representative sub-sample of ground tissue was taken and P determined.

Grain samples of wheat were taken from each plot at harvest time to analyze for P and N. Phosphorus determination was made on all of the samples. Nitrogen content of grains was determined on the samples which were taken from the plots receiving "0" and "80" lbs. P₂O₅/A.

CHAPTER IV

RESULTS AND DISCUSSION

Field Experiment

Yield data from the 17 harvested grain sorghum tests are reported in Table III and from the 23 wheat tests in Table VII.

Grain Sorghum Tests

Yields obtained varied widely among locations. Maximum yields varied from a low of 3,890 lbs/A in test 3 to 8,360 lbs/A in test 16. Yields were increased significantly by phosphate fertilization at 8 locations (Table IV). At sites 2 and 6, responses were significant at the 1 percent level and at the 5 percent level at sites 7, 11, 19, and 20 with a response at a slightly higher confidence percentage at sites 4 and 8.

Response predictions with current soil testing procedures for P were good. The predicted and measured yield responses are summarized in Table V. At sites 3, 15, and 17 increased yields would have definitely been predicted based on P tests, but none were obtained. The CV values were unusually large, which probably is an indication that any potential responses from applied P were not measured due to the large experimental error. At sites 7 and 19, a yield increase from applied P would definitely not be expected, but significant responses were measured. No explanation for the discrepancy between soil test values and response

TABLE III
 GRAIN SORGHUM YIELDS FROM SOIL FERTILITY PLOTS
 (EXPRESSED IN LBS./A)

Test No.	Fertilizer Treatments (P ₂ O ₅ #/A)					
	0	20	40	60	80	100
1	7314*	7398	7300	7694	7374	7162
2	6140	7386	6710	6990	7230	7010
3	3410	3480	3560	3840	3890	3540
4	7080	7370	7400	7740	7590	7480
6	4482	5204	4824	5332	4952	4602
7	4740	5280	5400	5360	5380	5150
8	6530	7230	7028	6946	7070	6690
11	5354	6496	6640	6840	6754	6274
12	4830	5172	5410	5010	4990	5350
13	5330	5330	4450	4710	4830	5550
14	5710	5280	6060	6230	5280	5066
15	3500	3580	3880	3920	3900	3490
16	8240	8280	8360	8330	8360	8180
17	3840	3940	3660	4080	4140	4310
18	4480	4840	4420	4920	4520	5020
19	4280	4610	5050	4820	5020	5210
20	6880	7320	7550	7360	7680	7040

*Each value is an average of 4 replications.

TABLE IV
ANALYSIS OF VARIANCE OF GRAIN SORGHUM YIELDS
OBTAINED FROM A STUDY IN THE FIELD

Test No. 1		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	147,181		
Trt.	5	125,596	0.66	
Error	15	190,334		

Test No. 2		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	490,121		
Trt.	5	782,616	10.02**	
Error	15	78,047		

Test No. 3		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	1,350,222		
Trt.	5	156,000	0.46	
Error	15	333,102		

Test No. 4		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	315,822		
Trt.	5	200,106	2.73	
Error	15	73,208		

TABLE IV (Continued)

Test No. 6		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	194,037		
Trt.	5	440,836	6.84**	
Error	15	64,392		

Test No. 7		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	28,688		
Trt.	5	253,186	3.32*	
Error	15	76,048		

Test No. 8		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	2,320,763		
Trt.	5	268,661	2.28	
Error	15	117,806		

Test No. 11		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	779,714		
Trt.	5	1,196,344	3.48*	
Error	15	342,942		

TABLE IV (Continued)

Test No. 12		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	791,291		
Trt.	5	202,008	1.15	
Error	15	175,227		

Test No. 13		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	1,504,888		
Trt.	5	743,306	0.08	
Error	15	926,382		

Test No. 14		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	495,064		
Trt.	5	888,354	1.63	
Error	15	543,458		

Test No. 15		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F.</u>	
Rep.	3	69,222		
Trt.	5	174,786	1.37	
Error	15	127,142		

TABLE IV (Continued)

Test No. 16		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	214,466		
Trt.	5	20,866	0.26	
Error	15	77,400		

Test No. 17		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	623,711		
Trt.	5	213,400	0.66	
Error	15	321,311		

Test No. 18		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	1,080,000		
Trt.	5	131,840	1.00	
Error	15	130,560		

Test No. 19		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	1,354,911		
Trt.	5	463,906	4.07*	
Error	15	113,897		

TABLE IV (Continued)

Test No. 20	Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>
Rep.	3	190,288	
Trt.	5	363,800	3.00*
Error	15	121,168	

**Indicates significance at 1 percent level of confidence.

*Indicates significance at 5 percent level of confidence.

TABLE V
 SUMMARY OF RESPONSES AND PHOSPHORUS SOIL
 TEST LEVELS (GRAIN SORGHUM)

Test No.	Soil Test P (lbs/A)	Response		C.V. (%)
		Predicted	Measured Level of Signifi- cance (%)	
1	70	No	N.S.	5.92
2	29	Yes	1	4.04
3	24	Yes	N.S.	15.94
4	44	--	10	3.63
6	36	Yes	1	5.18
7	173	No	5	5.28
8	39	Yes	10	4.96
11	27	Yes	5	9.16
12	39	Yes	N.S.	8.16
13	182	No	N.S.	6.12
14	58	No	N.S.	13.15
15	10	Yes	N.S.	9.61
16	56	No	N.S.	3.35
17	15	Yes	N.S.	14.19
18	63	No	N.S.	7.69
19	87	No	5	6.98
20	43	--	5	4.77

from these 2 locations can be given. Chemical analyses as reported in Table I reveal no major differences which could account for the discrepancies. Location 7 was mapped as a Richfield clay loam, whereas site 19 was mapped as Dalhart fine sandy loam; therefore, they varied widely in soil texture and presumably in chemical buffering capacity.

Percent sufficiencies at the responding locations ranged from 91.4 to 78.3 (Table VI). These yield increases from applied P fall within the broad ranges generally reported when sites 7 and 19 are eliminated. Unfortunately, soil test P values were not widely different at the responding locations when sites 7 and 19 are eliminated. Unfortunately, soil test P values were not widely different at the responding locations when sites 7 and 19 are not included. This limits interpretation of results based upon soil test values.

Wheat Tests

Grain yields are recorded in Table VII and the analysis of variance for each experiment in Table VIII. Yields varied widely from location to location due to climatic factors, soils, and crop management techniques. Maximum yields varied from a low of 22.04 bu/A at test site 20 to a high of 65.93 bu/A at location 17. Nitrogen deficiencies were observed during the growing season at several locations. Soils were too wet during the topdressing season for N applications at most locations.

Sites were selected for these studies which varied widely in soil test P levels with a preponderance of the sites testing in the range where some response to added P was expected. A summary of responses to added P and soil test values are recorded in Table IX. Nineteen of the locations had a test P level less than 50. Yields were increased from

TABLE VI
A COMPARISON OF PERCENTAGE SUFFICIENCIES AND SOIL TEST VALUES
AT RESPONDING GRAIN SORGHUM LOCATIONS

Test No.	Percent Sufficiency	<u>Soil Test</u> P. (lbs./A)
2	83.1	29
4	91.4	44
6	84.1	36
7	88.1	173
8	81.1	39
11	78.3	27
19	82.1	87
20	89.6	43

TABLE VII
 WHEAT YIELDS FROM SOIL FERTILITY PLOTS
 (EXPRESSED IN BUSHELS PER ACRE)

Test No.	Fertilizer Treatments (P ₂ O ₅ #/A)					
	0	20	40	60	80	100
1	44.66	46.36	42.29	44.44	38.37	46.02
2	53.50	47.94	49.62	50.16	54.34	53.69
3	36.44	35.06	34.30	34.98	36.54	39.73
4	33.30	34.90	36.54	36.49	37.30	34.14
5	50.91	53.75	49.94	51.43	53.88	55.29
6	41.38	43.30	43.10	43.11	43.84	39.43
8	36.54	41.48	41.00	41.51	42.86	48.06
9	22.69	23.88	25.96	22.71	21.34	21.66
10	62.00	57.35	60.71	57.53	57.94	48.55
11	37.49	42.57	48.51	43.30	42.08	40.57
12	42.70	39.89	44.45	44.70	48.40	40.35
14	38.94	39.56	39.73	38.10	38.20	40.64
15	27.18	26.71	29.86	31.07	28.66	29.40
16	36.89	42.89	38.51	41.57	37.57	38.81
17	56.12	62.96	65.15	65.93	64.85	64.17
18	56.29	50.59	50.05	52.32	50.91	55.48
19	23.63	25.98	23.20	25.20	24.15	19.39
20	20.53	21.82	22.04	22.88	21.34	21.74
21	23.50	23.12	22.61	23.31	22.82	22.69
22	25.15	26.76	26.98	26.39	26.61	26.73
23	24.39	23.50	22.34	23.34	24.68	24.76
24	22.39	23.28	22.54	22.79	23.21	23.18
25	26.28	29.09	28.60	25.06	27.25	28.39

TABLE VIII
ANALYSIS OF VARIANCE OF WHEAT YIELDS OBTAINED
FROM A STUDY IN THE FIELD

Test No. 1		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	13.15		
Trt.	5	35.42	1.17	
Error	15	30.15		

Test No. 2		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	192.63		
Trt.	5	27.93	0.49	
Error	15	56.93		

Test No. 3		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	1.19		
Trt.	5	15.23	0.48	
Error	15	31.30		

Test No. 4		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	13.33		
Trt.	5	9.86	0.96	
Error	15	10.18		

TABLE VIII (Continued)

Test No. 5		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	17.99		
Trt.	5	17.17	3.37*	
Error	15	5.08		

Test No. 6		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	100.08		
Trt.	5	89.48	1.39	
Error	15	64.20		

Test No. 8		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	9.04		
Trt.	5	54.58	0.62	
Error	15	87.62		

Test No. 9		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	36.84		
Trt.	5	11.38	0.56	
Error	15	20.21		

TABLE VIII (Continued)

Test No. 10		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	485.73		
Trt.	5	88.61	2.35	
Error	15	37.68		

Test No. 11		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	31.21		
Trt.	5	52.57	3.37*	
Error	15	15.55		

Test No. 12		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	443.77		
Trt.	5	39.91	1.89	
Error	15	21.10		

Test No. 14		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	128.32		
Trt.	5	3.80	0.42	
Error	15	9.03		

TABLE VIII (Continued)

Test No. 15		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	95.24		
Trt.	5	10.94		
Error	15	9.80		1.11

Test No. 16		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	76.38		
Trt.	5	22.10		0.46
Error	15	47.62		

Test No. 17		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	44.05		
Trt.	5	52.01		3.01*
Error	15	17.24		

Test No. 18		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	58.27		
Trt.	5	28.28		0.86
Error	15	32.65		

TABLE VIII (Continued)

Test No. 19		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	71.72		
Trt.	5	21.11	0.35	
Error	15	59.75		

Test No. 20		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	46.01		
Trt.	5	2.41	0.26	
Error	15	9.25		

Test No. 21		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	38.92		
Trt.	5	0.51	0.33	
Error	15	1.54		

Test No. 22		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	18.65		
Trt.	5	1.72	0.53	
Error	15	3.25		

TABLE VIII (Continued)

Test No. 23		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	22.22		
Trt.	5	3.51	0.56	
Error	15	6.26		

Test No. 24		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	10.66		
Trt.	5	0.57	1.23	
Error	15	0.46		

Test No. 25		Analysis of Variance		
<u>Source</u>	<u>df</u>	<u>M.S.</u>	<u>Cal. F</u>	
Rep.	3	85.25		
Trt.	5	9.59	0.56	
Error	15	16.99		

*Indicates significance at 5 percent level of confidence.

TABLE IX
SUMMARY OF RESPONSES AND PHOSPHORUS SOIL TEST LEVELS
(WHEAT)

Test No.	Soil Test P (lbs/A)	Response		C.V. (%)	Grain Protein (%)
		Predicted	Measured Level of Significance		
1	10	Yes	N.S.	12.57	14.48
2	22	Yes	N.S.	14.64	14.58
3	29	Yes	N.S.	15.47	15.40
4	29	Yes	N.S.	9.01	10.63
5	20	Yes	5	4.29	12.80
6	80	No	N.S.	18.20	12.85
8	65	No	N.S.	22.33	12.98
9	60	No	N.S.	19.52	16.48
10	41	Yes	N.S.	10.70	13.70
11	20	Yes	5	9.30	15.33
12	38	Yes	N.S.	10.58	14.40
14	40	Yes	N.S.	7.67	14.83
15	28	Yes	N.S.	10.87	9.43
16	113	No	N.S.	17.52	16.60
17	21	Yes	5	6.57	13.88
18	10	Yes	N.S.	10.86	14.13
19	30	Yes	N.S.	32.76	14.83
20	11	Yes	N.S.	14.01	7.90
21	21	Yes	N.S.	5.39	8.45
22	22	Yes	N.S.	6.82	10.40
23	15	Yes	N.S.	10.49	8.75
24	38	Yes	N.S.	2.97	9.18
25	26	Yes	N.S.	15.02	10.35

P application at only 3 of the locations (5, 11, and 17). At 6 of the locations (1, 2, 3, 15, 18, and 19) soil test values were low enough that definite yield increases were expected. But, the large CV probably accounts for no measured response, i.e., experimental error was perhaps too large. At sites 4, 20, 23, and 25 yields simply were held to a low level by N deficiency, thereby limiting responses to applied P. Also, the CV values were so large that responses could not be measured. At sites 21 and 22 even though CV values were small N deficiency was apparently the major factor affecting yields. This was verified by low grain protein concentrations. At sites 10, 12, 14, and 24 soil test P levels were above 35 and this amount of available soil P might be high enough to obtain a yield close to maximum, therefore P application on these locations had no effect on yields.

As contrasted to the sorghum studies, no increased wheat yields were obtained from P application where soil tests were high. No responses occurred with soil tests higher than 30.

The phosphorus concentration of the grain was measured on the wheat samples to determine: 1) the relationship of soil test P levels and grain P concentrations and 2) the effects of P fertilizer rates on grain P concentrations.

Grain P concentrations varied from 0.3 to more than 0.5 percent (Table X). Percentages of P in the grain were generally related to soil test values. A correlation coefficient (r value) of 0.70 was calculated for the P concentration of grain from those plots not receiving P fertilizer. This gives additional confidence in soil test values. In general, grain P concentration did not increase with increasing increments of applied P. These data are insufficient to ascertain

TABLE X
 PHOSPHORUS PERCENTAGE OF WHEAT GRAIN AS AFFECTED
 BY PHOSPHORUS FERTILIZER RATES

Test No.	Soil Test		Rate of P (P ₂ O ₅ /A)				
	P (lbs./A)	0	20	40	60	80	100
1	10	0.368	0.360	0.372	0.387	0.322	0.361
2	22	0.369	0.359	0.376	0.335	0.334	0.349
3	29	0.403	0.416	0.407	0.409	0.389	0.440
4	29	0.351	0.362	0.375	0.395	0.385	0.366
5	20	0.340	0.348	0.355	0.338	0.339	0.338
6	80	0.421	0.444	0.411	0.436	0.453	0.458
8	65	0.392	0.424	0.430	0.434	0.446	0.448
9	60	0.481	0.438	0.410	0.415	0.476	0.414
10	41	0.426	0.374	0.376	0.363	0.402	0.404
11	20	0.328	0.341	0.331	0.360	0.322	0.354
12	38	0.451	0.452	0.409	0.371	0.458	0.420
14	40	0.439	0.472	0.468	0.490	0.496	0.485
15	28	0.367	0.388	0.397	0.420	0.405	0.412
16	113	0.549	0.541	0.516	0.483	0.548	0.531
17	21	0.424	0.431	0.388	0.442	0.435	0.470
18	10	0.424	0.419	0.416	0.412	0.449	0.456
19	30	0.479	0.497	0.508	0.507	0.504	0.462
20	11	0.314	0.309	0.380	0.355	0.371	0.349
21	21	0.331	0.313	0.364	0.362	0.344	0.364
22	22	0.318	0.323	0.336	0.326	0.392	0.360
23	15	0.354	0.338	0.393	0.382	0.386	0.363
24	38	0.403	0.391	0.400	0.421	0.437	0.447
25	26	0.367	0.351	0.378	0.386	0.411	0.384

whether grain P concentrations can be a useful tool in monitoring P fertilizer needs, but from these limited data the concept shows some promise.

Laboratory Study

A Comparison of P Extraction Methods

Five soils from the grain sorghum tests with widely varying chemical properties were selected to compare three common P extraction methods. The objective of this study was primarily to determine the relationship between amounts extracted by the three methods on the various soils.

Phosphorus extraction. The amount of P extracted from the soil samples by the different solutions varied widely. These results are reported in Table XI.

TABLE XI

PHOSPHORUS EXTRACTED FROM THE SOIL SAMPLES BY DIFFERENT EXTRACTING SOLUTIONS (EXPRESSED IN PPM)

Test No.	Bray No. 1 (1:50)	Bray No. 1 (1:20)	NaHCO ₃ 0.5M
1	17	12	3
2	10	8	3
6	23	8	2
7	46	33	13
13	90	59	30

In comparing these three different extracting solutions, Bray No. 1 method with the soil-solution ratio 1:50 extracted the largest amounts of P. Smith et al. (42) found in both acid and calcareous soils that Bray No. 1 method with the soil-solution ratio 1:50 extracted more P and gave better correlation values than the ratio 1:7. In the present work, the ratio of 1:50 also extracted more P than the 1:20, but the correlation values were slightly better for the 1:20 soil-solution ratio.

The 0.5 M NaHCO_3 extraction method removed the smallest amounts of P of all the methods tested. The relationship between the amounts extracted and field responses was poorer. But, Olsen et al. (32) proposed that the 0.5 M NaHCO_3 method may be adaptable to a wide variety of soil conditions. However, the requisition of a certain previous skill for its manipulation may restrict this method as a widely used routine test procedure.

Correlation study. The percentage yields were obtained by dividing the yield of check treatments by the yield of 20 lbs. $\text{P}_2\text{O}_5/\text{A}$. These percentage yields are presented in Table XII.

For three of the extracting solutions employed, the correlation values between the amount of P extracted and the percentage yields were above 0.5. Table XIII shows the correlation values for the study.

Bray No. 1 (1:20) extracting solution gave the highest correlation coefficient. This was followed by Bray No. 1 (1:50). The NaHCO_3 method gave the lowest "r" value. However, the change in "r" values for these three methods was only 0.0218 between the highest and lowest.

Correlation coefficients based upon a small number of observations (5 soils) is insufficient for drawing definite conclusions, but the

TABLE XII
GRAIN SORGHUM FIELD PERCENTAGE YIELDS

Location		% Yield
Test No. 1	$\frac{7314}{7398} \times 100 =$	98.86
Test No. 2	$\frac{6140}{7386} \times 100 =$	83.13
Test No. 6	$\frac{4482}{5204} \times 100 =$	86.12
Test No. 7	$\frac{4740}{5280} \times 100 =$	89.77
Test No. 13	$\frac{5330}{5330} \times 100 =$	100.00

TABLE XIII
CORRELATION COEFFICIENT FOR GRAIN SORGHUM FIELD STUDY

Extraction Solution	Correlation Value (r)
Bray No. 1 (1:50 soil-solution ratio)	0.6003
Bray No. 1 (1:20 soil-solution ratio)	0.6168
NaHCO ₃	0.5950

results do indicate that the Bray No. 1 (1:20) extractant presently used in the Oklahoma Agronomy Soil and Water Testing Laboratory is as good for predicting P responses as the other two methods investigated.

Successive Extraction

The amounts of P obtained with successive extractions of Bray No. 1 (1:20) are shown in Table XIV.

TABLE XIV
AMOUNT OF P SUCCESSIVELY EXTRACTED FROM THE EXPERIMENTAL SOILS

Extraction No.	Amounts of P Extracted (pp2m)				
	Soil 1	Soil 2	Soil 6	Soil 7	Soil 13
1	23	13	20	53	132
2	13	10	20	28	51
3	8	8	23	15	23
4	20	5	20	10	15
5	13	5	13	8	13
6	10	5	10	8	13
7	5	3	8	8	10
8	8	5	10	10	10

In general, the amount of P removed per extraction decreased with increasing numbers of extraction. However, in Soil 1 more P had been removed at the fourth extraction than the previous one. This reaction

cannot be explained. Repeated tests with this soil gave essentially the same results. The eight successive extractions were not enough to reduce the P level to near zero. The total amount of P removed in eight extractions varied between 54 pp2m. and 267 pp2m. in the different soils. The accumulated amounts of P are illustrated graphically in Figure 1.

The successive extractions are related to the rate of "availability" which may govern the yield responses. The rate of "availability" involves the kinetics of P release and P supplying power of the soil for plant growth.

This phenomenon of continued P release is unique when compared with successive extractions of soils from more humid areas and helps explain the smaller incidence of P responses from the High Plains Region.

Recovery of Added Phosphorus

Knowledge concerning the recovery of applied P often helps explain phosphate responses to applied fertilizer on soils. This study was initiated to gain further information on the P chemistry of these selected soils.

After six weeks' incubation of the soil samples, the increase in Bray No. 1 (1:20) values from addition of P was determined. The result of the laboratory study is presented in Table XV.

The values in Table XV were obtained by subtracting the amount of P for the "0" pp2m. rate from the amounts of the remaining rates.

The amount of P recovered seldom equals the amount applied. When the amount of P recovered exceeds that applied, significant amounts of

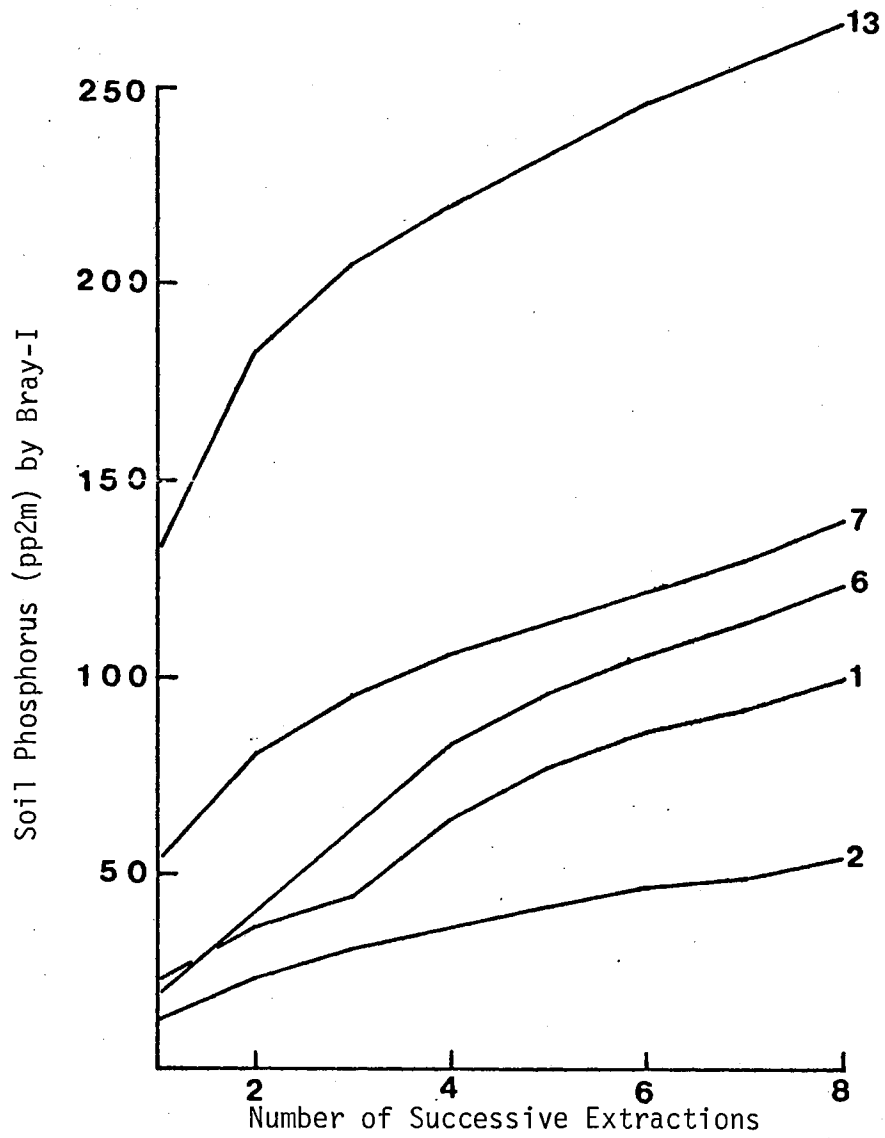


Figure 1. The Accumulated Amounts of Phosphorus Successively Extracted from the Experimental Soils

P may have been solubilized. Excess recovery or lack of recovery might also reflect random fluctuations in the extraction procedure. Lavery and McLean (24) found a range of 95-125% recovery of applied P and suspected both solubilization and fluctuation. In a later study Volk and McLean (53) used ^{32}P and found that fertilizer P did indeed have an effect on native P.

TABLE XV
RECOVERY OF APPLIED P TO THE EXPERIMENTAL SOILS
SIX WEEKS AFTER APPLICATION

P Added (pp2m)	Increase in Bray No. 1 P Extracted (pp2m)*				
	Soil 1	Soil 2	Soil 6	Soil 7	Soil 13
9	5	7	6	0	3
18	12	14	15	9	11
27	21	21	21	17	19
36	29	34	28	27	26
45	33	35	37	38	32
68	69	54	54	51	39
90	78	71	73	77	68

*Mean of the two replicates.

In this study a higher amount of applied P was measured than that commonly reported. Perhaps the applied P did not completely equilibrate with the soil, and some of the potential fixation was not complete. As expected, the percentage recovery increased with increasing increments

of applied P. The greatest variation between soils also occurred with the first increment. All soils tested were classified as Richfield clay loams and soil pH varied from 7.3 to 7.8. Differences between recoveries could not be explained by original soluble P contents.

Percentage recoveries of the applied phosphates are plotted against the rate of P added in Figure 2. The shape of the curves indicates that P saturation generally was reached at about 36 pp2m. of applied P. After saturation, percentage recoveries were in the 65 to 80 percent range. These data help explain the magnitude of field responses from small rates of applied P fertilizer.

Plant Analyses

In this present work, grain sorghum plants were sampled in three different growth stages from two selected field locations, measured, separated into parts and analyzed for content of P.

There was no significant difference in diameter of stems and in dry-matter weights of above-ground parts due to P applied. In test 6, however, a slight increase in dry-matter weights in leaves and stems was observed. The dry-matter weights of above-ground parts at three different growth stages are shown in Figure 3.

Figure 4 shows the percent P content in leaves and stems at three different growth stages in regard to the rate of P applied. In test 1 there was no evidence that shows the amount of P had any effect on the percent P content of leaf and stem. In test 6, however, the P content especially in leaves of the plant increased with increasing increments of applied P. It seems that the reason was the relatively low P content of the soil at this location. A significant increase in grain

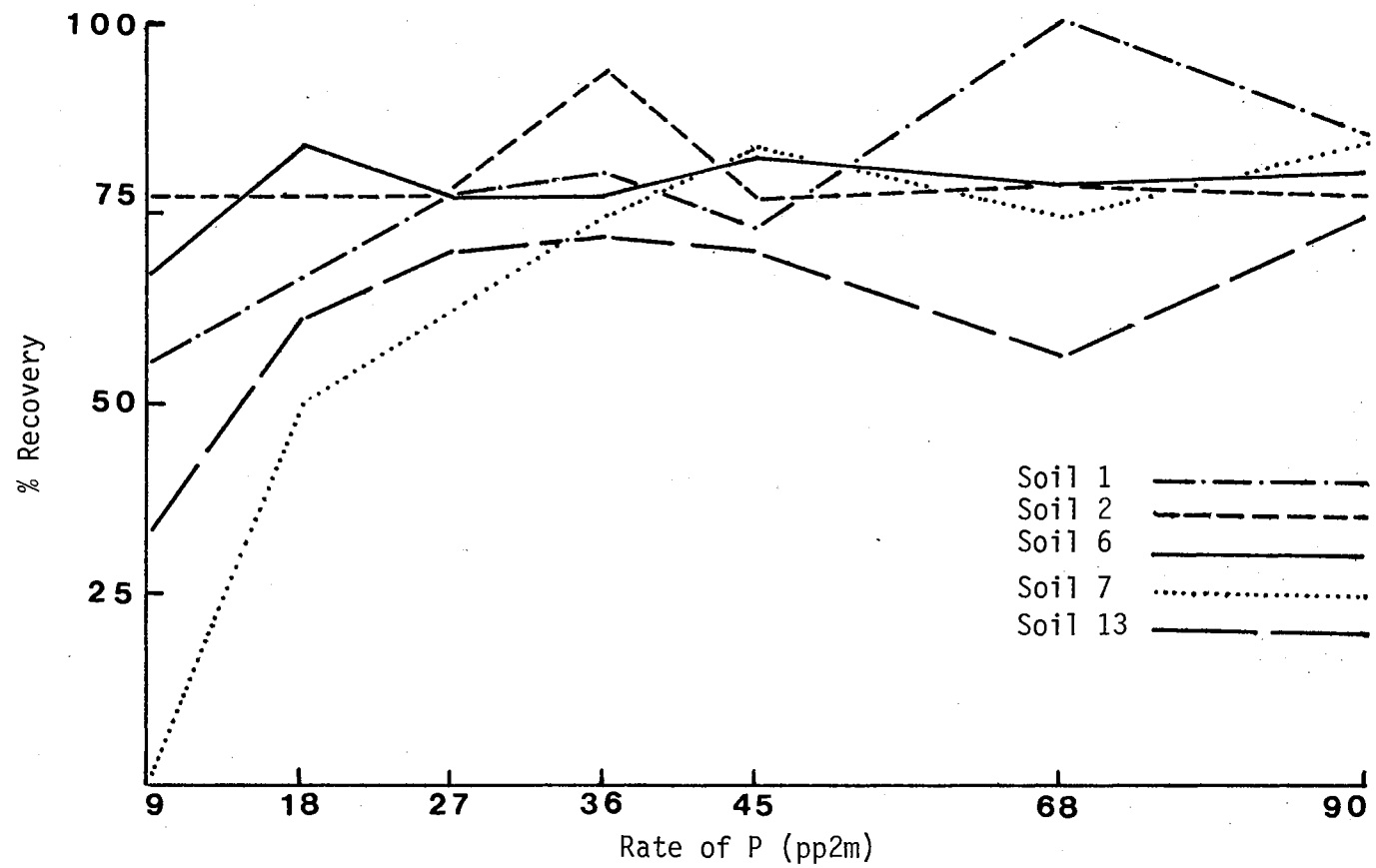


Figure 2. The % Recovery of Applied Phosphorus to the Experimental Soils 6 Weeks After Application

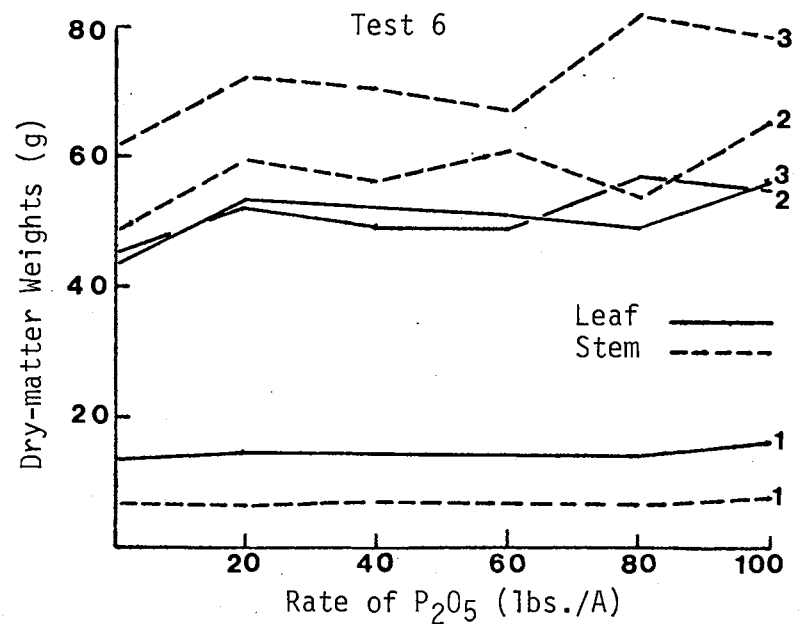
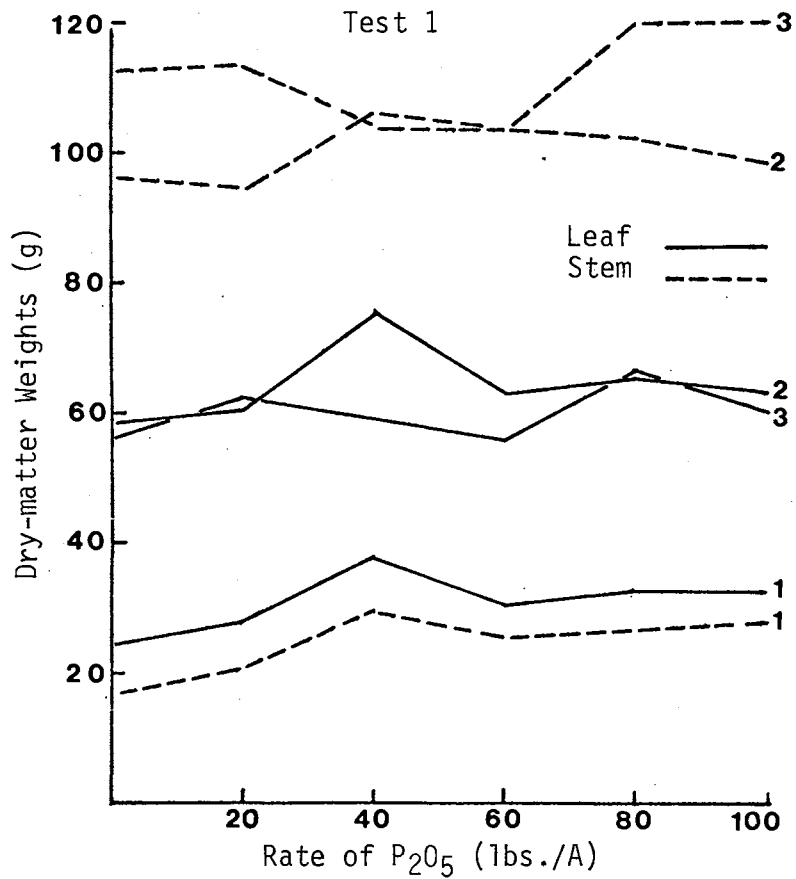


Figure 3. Dry-matter Weights of Leaves and Stems of Grain Sorghum in Three Growth Stages

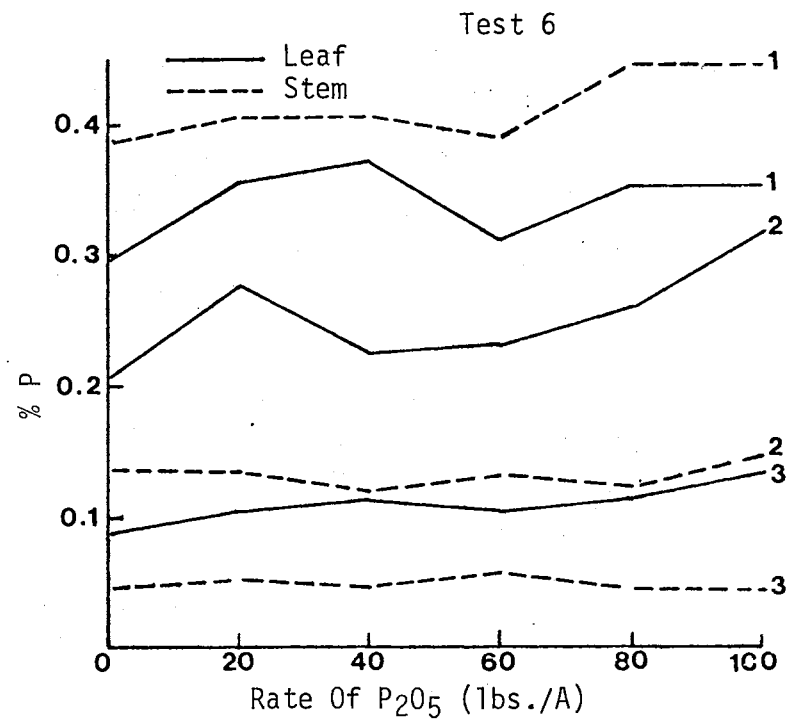
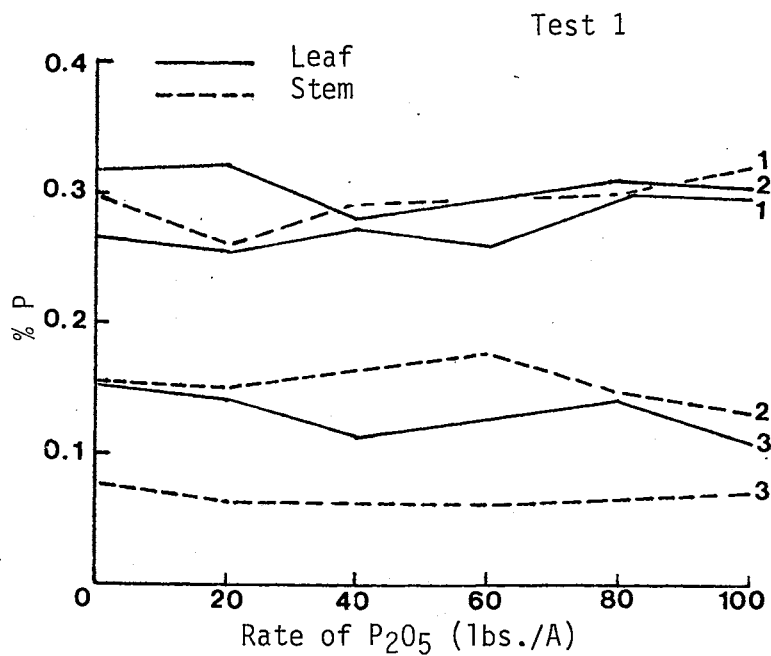


Figure 4. Phosphorus Levels in Grain Sorghum Leaf and Stem at Three Different Growth Stages

yield from applied P was measured at this location.

The P levels in leaves and stems are compared at three different growth stages in Figure 5. In the first stage, P content of stems varied from 0.26 to 0.32 percent in test 1 and 0.38 to 0.44 percent in test 6. These values are higher than the P content of leaves which were 0.25 to 0.29 percent in test 1 and 0.29 to 0.35 percent in test 6 at this stage. But opposite results were obtained in the second and third growth stages. The values of 0.06 to 0.07 percent in test 1 and 0.04 to 0.05 percent in test 6 for stems, and 0.12 to 0.15 percent in test 1 and 0.08 to 0.13 percent in test 6 for leaves were obtained in the third growth stage. It seems clear from these figures that, during the early growth stages, P content of stems was higher than leaves, but, in the later growth stages leaves contained a higher concentration than stems. This proves that P is translocated in the younger tissues. Also, it is understood that P percentage of the plant decreased throughout the growth cycle.

There was a close relationship between yield and P supply in test 6. Comparing these two experimental sites, the second location (test 6) had a lower soil test value for P and for this location P was probably the limiting factor on the yield. Consequently, significant yield response was obtained by supplying this nutrient in this experiment.

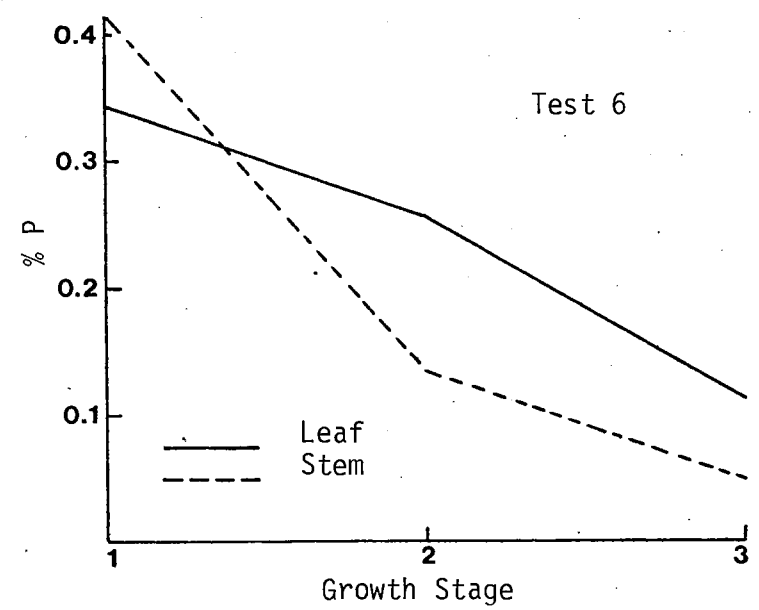
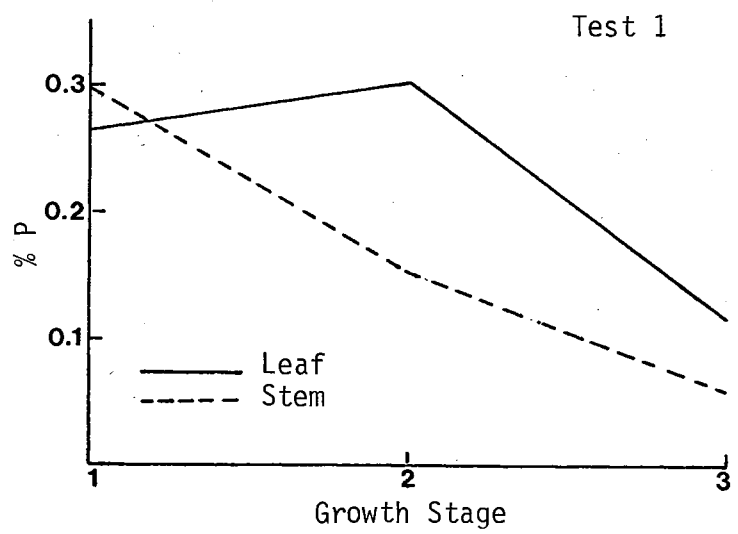


Figure 5. The Comparison of Phosphorus Levels in Leaves and Stems of Grain Sorghum at Three Growth Stages

CHAPTER V

SUMMARY AND CONCLUSIONS

Twenty-three field tests for wheat and 17 for grain sorghum were conducted to study the influence of 6 P fertilizer levels applied on the yield of winter wheat and grain sorghum in the Panhandle area of Oklahoma.

Laboratory studies were made with soils collected from the 5 different grain sorghum test locations. These soils were used to evaluate the following methods of extraction for available P:

- 1) 0.5 M NaHCO_3 adjusted at a pH of 8.5 with a soil-solution ratio of 1:20 and
- 2) Bray No. 1 method, 0.025 N HCL + 0.03 N NH_4F with two soil-solution ratios of 1:20 and 1:50.

An attempt was made to correlate grain sorghum yields with soil tests for available P.

On the same soil samples, successive extracting for available P and recovery of added P were investigated in an effort to ascertain the P supplying power of the soils in laboratory conditions.

Effects of P fertilizer treatments on P uptake by plants were studied. From the two selected grain sorghum tests, plant samples were collected at three different growth stages and P analyses were made separately in leaves and stems. Protein and P content of wheat grain samples taken from each plot were also determined.

From the field and laboratory studies, the following conclusions seem justifiable:

1. Soil test procedures (Bray No. 1, 1:20 soil-solution) currently being used are generally reliable in predicting where responses to added phosphate fertilizer can be expected but from these studies the magnitude of responses was not predictive with the soil tests.

At two sites increased yields of grain sorghums were measured where soil test levels were considered high.

In the wheat experiments no increased yields from fertilizer P were measured on soils testing above 30 lbs. per acre with the Bray No. 1 (20:1) extraction.

Where responses to added P were obtained, the first increment (20 lbs P_2O_5/A) was generally sufficient.

2. A good correlation was found between soil test P and P concentration in the wheat grain but the data were insufficient to establish "critical" concentration values.
3. Recoveries of applied P to 5 of the High Plains soils were quite high and P saturation was reached with only 36 pp2m of applied P in the laboratory tests.
4. P concentrations in grain sorghum forage varied widely between 3 stages of growth. The P concentration decreased with growth. During the early growth stages, P concentration of the stems was higher than the leaves but near maturity leaves contained a higher concentration than stems.

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APPENDIXES

TABLE XVI
LOCATIONS OF GRAIN SORGHUM TESTS

Test No.	Farmer	County	Location
1	Ronnie White	Texas	7E-1N, Guymon
2	Ted Summers	Texas	2S-1E, Guymon
3	Walter Niedens	Texas	6SW of Hooker
4	Ewing Mathis	Texas	West of Hough-Elkhart Hwy. Junction
6	Bert Grace	Texas	1 $\frac{1}{2}$ N-1 $\frac{3}{4}$ W, Goodwell
7	Arnold Beck	Texas	5S-2 $\frac{1}{2}$ E, Goodwell
8	Ewing Mathis	Texas	$\frac{1}{2}$ S, Guymon
11	Calvin Brown	Cimarron	12S- $\frac{1}{4}$ E, Keys
12	John Barnes	Cimarron	2N, Boise City
13	Mike Barnes	Cimarron	2 $\frac{1}{2}$ W=3 $\frac{1}{4}$ N, Boise City
14	Vernon Powers	Cimarron	2N-2 $\frac{1}{2}$ E, Boise City
15	Claud Frazee	Beaver	3 $\frac{3}{4}$ E-2S, Elmwood
16	C. B. Mounds	Beaver	5S, Balke
17	Cletus Carter	Beaver	9W, Fargo
18	Lawrence Wiens	Beaver	3N-8E, Turpin
19	Lawrence Wiens	Beaver	4N-5E, Turpin
20	John Peters	Beaver	4N-1E, Turpin

TABLE XVII
LOCATIONS OF WINTER WHEAT TESTS

Test No.	Farmer	County	Location
1	King Brothers	Texas	18N-1½W, Guymon
2	Eldon Wessler	Texas	11N-2W-½S, Guymon
3	Clyde Fischer	Texas	1½N, Optima
4	Eugene Miller	Texas	8E-3½S, Guymon
5	Virgil Higgins	Texas	8E-1S, Guymon
6	George Burgner	Texas	3½W, Texhoma
8	Chuck Hawkins	Cimarron	1½N, Boise City
9	Chuck Hawkins	Cimarron	1½N-1½W, Boise City
10	Lawrence Powers	Cimarron	1½N, Boise City
11	Ronnie White	Texas	7E-½N, Guymon
12	Warren Headrick	Beaver	2W, Turpin
14	John Schmidt	Beaver	3N-5E-1/8N, Turpin
15	Cletus Carter	Beaver	3N-10E, Turpin
16	Denzel Cates	Beaver	7S-2W, Elmwood
17	C. B. Mounds	Beaver	5S-½E, Balko
18	Richard Goodlow	Texas	1½N-1½W, Hough
19	J. R. Rowan	Texas	5W-¼S, Goodwell
20	Willard Cosby	Harper	6W, Buffalo
21	Max Barth, Jr.	Harper	3/4S, Buffalo
22	Willard Cosby	Harper	5W, Buffalo
23	Kenneth Schoenhols	Ellis	2½S, Shattuck
24	Harold Imke	Ellis	5½S, Shattuck
25	Vernon Becker	Ellis	1E, Shattuck

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