A STUDY OF SOME PROBLEMS REGARDING SOIL SAMPLING, SOIL TESTING, AND FERTILIZER RECOMMENDATIONS IN OKLAHOMA

By

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A STUDY OF SOME PROBLEMS REGARDING SOIL

SAMPLING, SOIL TESTING, AND FERTILIZER

RECOMMENDATIONS IN OKLAHOMA

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CHAPTER I

INTRODUCTION

Regular research is conducted in conjunction with a good soil testing service to provide current information on field conditions in the service area. Information can be obtained which is the basis for proper soil sampling and fertilizer application recommendations. The same holds for reliable soil test procedures. In some instances, erroneously low values for soil phosphorus content have been obtained in Oklahoma by use of the Bray P-1 extracting method (Bray and Kurtz, 1945) on soils of high pH and $CaCO_3$ content. These low values indicate phosphorus deficiencies for in excess of those existent and, as a result, predict the need for far more fertilizer than actually needed to make up for the deficiency (Westerman, 1979). An area which contained soils testing erroneously low in phosphorus was found near Cordell, Oklahoma. Experimental sites were chosen on which soil sampling and fertilizer recommendations research could simultaneously be conducted.

Objectives of this study consist of the determination of a soil sampling procedure for a terraced field; an assessment of the Oklahoma nitrogen fertilizer calibration; thirdly, determination of the percent sufficiency of various levels of soil phosphorus in producing a wheat crop; fourthly, the determination of crop response to fertilizer phosphorus applied either in a band or broadcast and disced in; and, fifthly, determination of the extractant - Bray P-1 (Bray and Kurtz, 1945) or Mehlich (Mehlich, 1978), and soil:extractant ratio producing representative phosphorus soil test values on high-pH soils.

CHAPTER II

LITERATURE REVIEW

Chemical Extraction of Phosphorus From High-pH Soils

Certain factors must be considered in development of a procedure for extracting phosphorus from high-pH soils, particularly calcareous high-pH soils. One is the refixation of phosphorus during extraction. In calcareous soil, some phosphorus is fixed in the form of calcium-magnesium phosphates. The extractant may extract phosphates from the soil, yet in secondary reactions phosphorus may be "refixed" and the phosphate ion concentration artificially reduced. Two techniques are used to prevent this refixation: 1) use of a wide soil:solution ratio (which prevents appreciable fluctuation in pH and 2) sufficient buffering of the extracting solution, sometimes involving the use of complexing agents (Nelson et al., 1953).

Bingham (1961) collected data from state soil testing services all over the nation on extractants used for phosphorus testing. He pointed out that in some western states, two extractants were used - one for acid soils and one for alkaline soils. Thus, two separate calibrations are required in those states. The large number of proposed phosphorus extraction methods indicates adaptation over a limited range of soil conditions with poor crop growth correlations over a state or region

(Long and Seatz, 1953).

Several authors have reported the results of studies comparing the relative performances of various solutions in extracting phosphorus from calcareous high-pH soils. A study conducted in Nebraska (Olsen et al. 1954a) evaluated four extractants - Bray P-1 (0.03 N NH_4F-0.025N HCl, Bray and Kurtz, 1945). Olsen's $NaHCO_3$ (Olsen et al., 1954a), Nebraska buffer (buffered acetic-boric acid, Olsen and Rhodes, 1953), and Truog's buffer (0.002 N H_2SO_4, pH 3, Trug, 1930). Results showed Bray's P-1 and Olsen's $NaHCO_3$ to be superior over a wide range of soil acidities, textures, and calcium contents to the other two methods both in relating to Dean's A value (Fried and Dean, 1952) and in correlating to crop response. Dean's A value represents the amount of soil phosphprus equally available to the phosphorus added in a reference fertilizer and thus measures a soil's available phosphorus.

Olsen et al. (1954b) evaluated the availability of phosphorus in long-time rotations on calcareous soils using the A value. They compared this value to various chemical extraction methods which might be used to predict it. Methods used were Olsen's $NaHCO_3$ (Olsen et al. 1954a), surface P (Olsen, 1953), Bray P-1 (Bray and Kurtz, 1954), CO_2 (Stanberry, 1949), H_2O (Bingham, 1949). All correlations between the A values and methods were significant, with the exception of that with CO_2.

Pack and Gomez (1956) reported from New Mexico on a study designed to compare some of the more highly recommended tests for alkaline soils. Four extractants used were CO_2 (Stanberry, 1959), Olsen's $NaHCO_3$ (Olsen et al. 1954a), water (Bingham, 1949), and Bray P-1 (Bray and Kurtz, 1945). Findings indicate that water-soluble phosphorus gives the best correlation with crop response on these soils. Pack and Gomez (1956) remark that the $NaHCO_3$ test may merit further consideration because of its close correlation with the water test. Furthermore, the Bray P-1 and $NaHCO_3$ extractants removed much more phosphorus from the soil than did the CO_2 and water methods.

Smith et al. (1957), conducted a study investigating various acid-fluoride solutions such as the one employed in the Bray P-1 extractant, using calcareous soils of western Kansas. Solutions investigated included 1) 0.1 N HCl, 2) 0.1 N HCl + 0.3 N NH_4F, 3) 0.025 N HCl, 4) 0.25 N HCl + 0.03 N NH_4F or Bray's P-1 (Bray and Kurtz, 1945), 5) 0.025 N HCl + 1.0 N $CaCl_2$, and 6) Olsen's 0.5 M $NaHCO_3$ buffered at pH 8.5 (Olsen et al., 1954a). These researchers found that correlation between crop yield response and extraction of phosphorus were higher for the Bray P-1 extractant at a soil:solution ratio of 1:50 than for any other extractant used. The correlation for Olsen's extractant was far below that obtained for Bray's, yet substantially above the values for the four other solutions.

Relatively high phosphorus values resulted from soil extraction with 0.1 N HCl either alone or in 0.03 N NH_4F, or extraction with 0.025 N HCl alone. With the addition of 0.03 N NH_4F to the 0.025 N HCl (Bray P-1), the amount of phosphorus extracted markedly decreased. Repression of the solubility of phosphorus in 0.025 N HCl by the addition of 1.0 N $CaCl_2$ was much less marked than the repression caused by addition of fluoride ion in NH_4F. Concerning relative concentrations of HCl and NH_4F, the combination used in the Bray P-1 solution produced the most accurage results. Increasing the concentration of HCl to above 0.03 N or that of NH_4F to 0.04 N seriously decreased the HCl - NH_4F

combination's effectiveness as measured by correlation values.

Also, soil:solution ratios were investigated. A small soil:solution ratio (1:7) in use with Bray P-1 extractant resulted in very low correlations between available phosphorus and yield. A wide ratio (1:50) gave a much higher degree of correlation. However, the use of the ratio 1:100 offered no advantage over a ratio of 1:50. The H^+ in the extractant reacts with $CaCO_3$ in the soil. Seemingly the ratio of 1:50 provides extractant with sufficient H^+ to react with a calcareous soil of 6.25 percent $CaCO_3$ content. The smaller ratio allows for sufficient H^+ to react with a soil of only 0.87 percent $CaCO_3$ content. These results indicate that changes in the soil:solution ratio might serve as a more effective technique for estimating plant availability of phosphorus in calcareous soils then changing the acid:fluoride ratio.

Smith et al. (1957) also extracted phosphorus from 1 g samples of chemical compounds to analyze the action of fluoride ions on various chemical forms of phosphorus. Fluoride ions displayed a tendency, when present with 0.025 $\underline{N}$ HCl, to repress the solubility of phosphate in either tribasic combinations, or in rock phosphate. It did not seem to depress the solubility of mono- or di- basic calcium phosphates. Apparently, the success of the Bray P-1 combination of acid and fluoride is due to the repressive effect of the fluoride ion on forms of phosphorus (tri-basic combinations) commonly recognized as being of very low avialability to plants. The phosphorus extracted seems to accurately represent the soil phosphorus available to plants in these calcareous soils.

Tisdale and Nelson (1975) summarize much of the preceeding discussion:

Extracting solutions, ranging from water, alkalies, and weak

> acids all the way to relatively strong acids containing ammonium fluoride, have been used for the extraction of phosphorus. In a study conducted by the Soil Test Work Group on a wide range of soils over the United States the Bray No. 1 method, which employs 0.025 N HCl + 0.03 N NH_4F, gave especially good correlation with A values in the greenhouse and with crop response. Olsen's method of employing 0.5 N $NaHCO_3$ has been satisfactory on alkaline soils. Strong acids cannot be used in alkaline soils because the tri- calcium phosphate, which is not available to crops, is dissolved out. Mehlich's 0.05 N HCl + 0.025 N H_2SO_4 and the Morgan sodium acetate extractants have been popular in some areas (p. 469).

The Soil Test Work Group referred to is the Fitts (1956) reference.

Considerable data has accumulated on the solutions developed by Bray and Olsen. In California, workers (Martin and Mikkelsen, 1960) found the water and $NaHCO_3$ extractants to be reliable for measuring phosphorus available to grains planted on a wide variety of acid to alkaline soils. Bingham (1961) noted that alteration of soil:solution ratios or time of extraction can greatly reduce the significance of estimated soil test values.

Syers et al. (1972) point out that the Bray P-1 extractant appears to have been used either routinely or experimentally in almost every other country where soil testing is practiced. Fitts (1956) concluded that the Bray test was least affected by soil differences, among the soil tests made by 55 commercial soil testing laboratories on 74 soils. Yet Smith's previously mentioned work (1957) plus those of Manuca et al. (1964), Koswara and Hanway (1969), and Randall and Grava (1971) predict decreased performance of the Bray P-1 test on calcareous soils.

Manuca et al. (1964) in Rumania found a lower correlation of Bray P-1 (Bray and Kurtz, 1945) with phosphorus uptake than that of any of three other methods; the Egner-Rhiehm (Thun et al., 1955), Riehm (Riehm, 1940), and Arrhenius (Arrhenius, 1929) methods. In those soil samples which were unfertilized, this low correlation was attributed to the unsuitability of the Bray extractant for those soil samples calcareous and containing calcium phosphates. On the fertilized samples, highest correlations were obtained by the Bray method probably because the added phosphorus is bound predominantly in an adsorbed, exchangeable form which is well detected by the Bray method. Also, Susuky et al. (1963) found a low negative correlation between the Bray method and calcium phosphates.

Blanchar and Caldwell (1964) researched the suitability of five extractants for available phosphorus determination on calcareous and noncalcareous soils. The five extractants were 1) Bray P-1 (Bray and Kurtz, 1945) 1:10 ratio, 2) Bray P-1 (Bray and Kurtz, 1945) 1:50 ratio, 3) Morgan (Morgan, 1941), 4) Olsen's $NaHCO_3$ (Olsen et al. 1945a), and 5) water (Bingham, 1949). For the calcareous soils, all methods except Bray at a 1:10 ratio were suited for phosphorus testing, as determined by correlation with plant uptake of phosphorus. The correlations of Bray 1:50 and Morgan were highly significant.

Soil chemical properties affecting plant uptake of phosphorus were also investigated. The amount of calcium carbonate equivalence (CCE) was not correlated with phosphorus content, although the lime content was. Blanchar and Cladwell (1964) remark that since amounts of phosphorus extracted by the various methods differed between soil groups (calcareous vs. noncalcareous), extractants can be chosen for each group which accurately characterize plant available phosphorus.

Randall and Grava (1971) noted the increasing difficulty of soil testing laboratories to accurately determine available phosphorus on calcareous Minnesota soils by use of the Bray extractant at a ratio of

1:10. This difficulty is caused by the use of higher rates of phosphate fertilizers. For several years uniform heavy rates of phosphate have been applied to calcareous fields; yet often the soil test phosphorus values tend to vary greatly. In many instances, low values still occur. Concurrently, differential crop growth and yield response to phosphate applications have not generally appeared. Previously discussed studies plus that of Peck (1962) present the Bray P-1 method as probably the most practical test for available phosphorus where a large number of samples is processed. Others indicate possible problems with the Bray test, and Randall and Grava (1971) seek to further characterize the behavior of the Bray P-1 solution in soils.

When the Bray extractant is used at a soil:solution ratio of 1:10, only enough H^+ from HCl is present to neutralize 0.0125 g of $CaCO_3$, or 1.25 percent $CaCO_3$. To increase the ratio to 1:50 or 1:100 increases the amount of $CaCO_3$ neutralized to 6.25 percent and 12.5 percent, respectively. Soils containing carbonates, primarily calcitic in nature, have the ability to neutralize considerably more acid than do soils containing dolomitic carbonates (which generally react more slowly with the acid). Possibly a longer shaking time would reduce this difference.

Randall and Grava (1971) further state that the fluoride ion contained in the Bray P-1 extractant should theoretically extract phosphorus. However, F^- may be deactivated by the calcium contained in these calcareous soils. Possibly during extraction the reaction $Ca^2 + 2F^- = CaF_2$, $K_{sp} = 4 * 10^{-11}$ (26^oC) occurs. So, deactivation of F^- plus neutralization of the dilute HCl could explain the effect of calcium carbonates in repressing the extraction of phosphorus with the Bray P-1 solution.

The authors determined the variability of extractable phosphorus on highly fertilized calcareous soils where three different soil: solution ratios (1:10, 1:50, and 1:100) were used. Generally, the variability was greatly reduced in all samples when the wider ratios of soil to extractant were used. This would indicate that more accurate and consistant determinations of phosphorus from highly fertilized calcareous soils could be made if wider ratios of soil to Bray P-1 extractant are used.

Some form of phosphorus fixation during the acid extraction of soils with very dilute acids is to be regarded as the rule rather than the exception (Cooke, 1951). Blanchar and Caldwell (1964) believe that this is the result of the neutralization of acid by $CaCO_3$. But Smith et al. (1957) present evidences that presence of the F^- ion represses phosphorus extraction. Syers et al. (1972) showed that the CaF_2 formed by the reaction of calcite with 0.05 N NH_4F immobilizes a considerable portion of the phosphorus released during this extraction. Results obtained by Williams et al. (1971) agree with this conclusion about CaF_2. Thus, the formation of CaF_2 in the presence of phosphorus can be monitored by the extent to which phosphorus immobilization occurs. Syers et al. (1972) conducted a research program to measure formation of CaF_2 during the extraction of calcareous soils with the Bray P-1 solution; also to assess the degree to which CaF_2 formation can explain underestimation of available phosphorus by Bray P-1 extraction.

Removal of phosphorus from calcite samples with 0.03 N NH_4F in combination with varying concentrations of HCl was studied. Phosphorus removal was virtually complete with NH_4F solutions containing 0.10, 0.025, and 0.05 N HCl, indicating the formation of phosphorus-fixing

CaF_2 during extraction. Without HCl, fluoride had little or no effect on the sorption of phosphorus by calcite at this very low concentration of fluroide and short reaction time of one minute. But in combination with 0.1 N HCl, no phosphorus was removed from solution. This amount of H^+ was sufficient to dissolve all of the $CaCO_3$. These results indicate that if the acid added with the Bray reagent is neutralized, phosphorus will be neutralized by the CaF_2, and decreased extraction of phosphorus resulted from high calcareous soils. Thus, to overcome this problem, an increase in the soil:solution ratio or in the acid concentration may be successful in overcoming the problems associated with the use of Bray's solution on calcareous soils.

Syers et al. (1972) caution from the work of Cooke (1967) that if the $CaCO_3$ has associated phosphorus or if large amounts of acid soluble phosphorus are dissolved from the soil components or from apatite, available phosphorus may be seriously overestimated. Syers et al.'s work indicated that repressive effect of F^- on phosphorus extraction shows up to a greater extent on high phosphorus status soils than on the other calcareous soils used in the study. Therefore, on these soils, erroneous fertilizer recommendations could very well be made. Especially low phosphorus status soils may cause problems as they continue to be assessed as having low phosphorus status even though with time the phosphorus status has been already raised sufficiently by application of fertilizer.

Mehlich (1978) reported on an extractant designed to allow for elimination of the need for the grouping of soils. This extractant, 0.2 N NH_4Cl - 0.2 N HOAc - 0.015 N NH_4F - 0.012 N HCl at pH 2.5, is designed to allow simultaneous extraction of several plant nutrients over a wide range of soil properties. Mehlich compared the performance of his extractant with those of Bray's and Olsen's extractants and with double-acid ("DA,"-0.05 N HCl - 0.025 N H_2SO_4 - Mehlich, 1953) and DAF (DA + 0.08 N NH_4F). The DA extractant is not recommended for calcareous soils because it extracts phosphorus far in excess of that extracted by Bray's or Olsen's solutions. The new Mehlich extractant is designed to be held to a pH of 2.5 because the advantages of the F^- ion in selectively extracting available forms of phosphorus, when combined with 0.025 N HCl, do not also apply to the extraction of calcium unless the pH is held below 2.9.

The new extractant was highly comparable with Bray P-1 (Bray and Kurtz, 1945) and Olsen's $NaHCO_3$ (Olsen et al., 1954a) on a number of soils with a wide range of properties. Soils were divided into three groups based on type of phosphate compounds contained in them. Of the four extractants tried, the deviations from the means of phosphorus values between the extreme soil types was smallest for the new extractant. This indicates that the need to establish different phosphorus calibrations for widely differing soils was least with the new extractant.

Current Oklahoma Nitrogen Recommendations and Phosphorus Percent Sufficiencies

Fact Sheet 2225, Oklahoma State University (Johnson, G. and B. Tucker) contains data currently in use in calibrating soil nutrient test values to fertilizer required.

Representative Sampling of Soil

A premise underlying accurate testing of a problem is that the sample taken for testing represents the entire problem area. Discussions of the philosophy of representative samples can be found in any statistics text, such as Steel and Torrie (1960).

Band-Placement of Phosphorus Fertilizer

The thesis of De Wit (1953) contains much of the theory describing current conceptions of the performance of band-placed fertilizer. A large body of literature now supports band-placement as a technique allowing more efficient plant utilization of fertilizer material (Tisdale and Nelson, 1975).

CHAPTER III

MATERIALS AND METHODS

Field Experiments

Four experiments were initiated in October, 1979 near Cordell, Oklahoma. Two experiments were initiated on each of two farms, a farm east of Cordell and one west of Cordell. All fertilizer formulations and treatments are reported in elemental form. The test crop was wheat.

East Farm

Crop response to phosphorus fertilizer was studied on the east farm. One experiment consisted of treatments arranged in a randomized complete block design. Treatments incorporated different rates and methods of placement of fertilizer phosphorus. The other experiment was designed to study the variation in crop response up a terraced hillside to a constant and adequate rate of fertilizer phosphorus and nitrogen. In past production years, soils on the east farm had displayed a deficiency of nitrogen and phosphorus, and the phosphorus soil testing problem discussed in previous sections had been encountered.

The east farm is located one mile east and two miles south of Cordell, Oklahoma in Sec. 11, T.9N, R17W. of Washita County. The phosphorus method-of-placement experiment was conducted on a Carey silt loam, 3 to 5 percent slopes (fine-silty, mixed, thermic Typic

Argiustoll) located on the level upland at the top of the slope containing the terraced phosphorus experiment. The terraced phosphorus experiment was conducted on an Obaro silty clay loam, 2 to 5 percent slopes, eroded (fine-silty, mixed, thermic Typic Ustochrept).

The phosphorus method-of-placement area consisted of eight treatments (Table I), treatments two through eight completely randomized within each of the four replications. Plots measured 22.8 meters by 4.9 meters each. The four plots of complete check treatment, treatment number one, had been omitted at the initiation of the experiment and were added on at grain harvest to the east end of each replication. No fertilizer had been applied to these check plots at any time during the growing season.

On October 10, 1979, the experimental site was laid out and the soil of each replication sampled. Samples consisted of a composite of 20 cores taken from the top six inches of soil. Fertilizer treatments were applied. The ammonium polyphosphate banded with the seed was metered out by means of a John Blue squeeze pump mounted on a John Deere combination grain drill/fertilizer spreader. The ammonium polyphosphate was contained in a stainless steel tank mounted above the pump, the pump being propelled by a ground drive wheel. After passing through the pump, the ammonium polyphosphate passed into a tube mounted on each grain spout and thus as the grain was drilled the ammonium polyphosphate was placed in a band alongside the seed. The triple superphosphate (0-20-0) and the ammonium nitrate (34-0-0) were broadcast by the fertilizer spreader and disced in.

Forage samples were taken in March 1980 by clipping the upper 15.2 cm of plant material at each of 20 locations within each plot and then

TABLE I

SOIL TYPE AND FERTILIZER TREATMENTS, PHOSPHORUS METHOD-OF-PLACEMENT EXPERIMENT, CORDELL, 1979-1980

Location	Soil Type	Treatment Number	Treatments: N-P-K	Treatments: Phosphorus Method of Placement
Cordell	Carey	1	0-0-0	
East	silt loam	2	+80-0-0	
Farm	(Typic			
	Argiustoll)	3	80-20-0	*Broadcast and
		4	80-40-0	disced in
		5	80-80-0	
		6	(80+6)-20-0	**Banded with seed
		7	(80+12)-40-0	
		8	(80+24)-80-0	

+Fertilizer material: ammonium nitrate (34-0-0).
*Fertilizer material: triple superphosphate (0-20-0), elemental form.
**Fertilizer material: ammonium polyphosphate (10-15-0), elemental form.

combining these clippings for each plot. On June 13, 1980, plots were harvested and grain yield determined. A model A Gleaner combine was used to harvest the middle 3.05 m of each plot, the grain from each plot being collected in individual burlap sacks and weighed. A laboratory sample of grain was taken from each sack.

The terraced phosphorus experiment consisted of four terraces, plus the level areas below each terrace. On October 10, 1979, four 4.9 m wide strips parallel to the terrace contours were laid out along the level areas. The soil of each strip was sampled as that of the replicated area was, twenty cores being taken per strip. The strips were fertilized, ammonium nitrate (34-0-0) and triple superphosphate (0-20-0) being broadcast and disced in (Table II). The last one-fourth of the strip below terrace three and all of the strip below terrace four did not receive nitrogen fertilizer, as the ammonium nitrate ran out. In May of 1980, four forage samples were taken by collecting a random sample of the flag leaves of wheat plants within each strip. On June 13, 1980, the grain was harvested for yield and laboratory samples were taken as for the method-of-placement experiment area. For simplicity the strips will be denoted by the number of the terrace above them; thus, "the strip on the level area below terrace one" will be called only "terrace one", etc. Terraces are numbered starting at the bottom of the slope. At harvest each of the four strips was marked off at four 15.2 m intervals, producing replications within each strip. An unfertilized strip parallel to and immediately alongside each treated strip was laid out and also marked off in 15.2 m plots corresponding to the fertilized plots. This paired-plot effect was desired in order to compare relative crop response on unfertilized and phosphorus-fertilized

TABLE II

SOIL TYPE AND FERTILIZER TREATMENTS, PHOSPHORUS TERRACED EXPERIMENT, CORDELL, 1979-1980

Location	Soil Type	Terrace Number	Treatments Rate of N-P-K
			-kg/ha-
Cordell	Obaro silty	Terrace 4	80-40-0
East	clay loam	Terrace 3	80-40-0
Farm	(Typic	3/4 of Terrace 2	80-40-0
	Ustochrept)	1/4 of Terrace 2	80-0-0
		Terrace 1	80-0-0

Fertilizer materials: ammonium nitrate
triple superphosphate (0-20-0), elemental form.

All fertilizer broadcast and disced in.

plots. Thus eight plots, four fertilized and four unfertilized, were harvested and yield determined and grain sampled.

West Farm

Crop response to nitrogen fertilizer was studied on the west farm. One experiment consisted of different rates of fertilizer nitrogen arranged in a randomized complete block design. The other experiment was designed to provide data for a study of the variation over a terraced area of soil nutrient contents. In past production years, soils on this farm had displayed the phosphorus soil testing problem discussed previously.

The west farm is located two miles west, one mile south, and one mile west of Cordell in Sec. 1, T.9N. R.18W, of Washita County. The terraced nitrogen experiment was conducted on an Obaro silty clay loam, 2 to 5 percent slopes, eroded (fine-silty, mixed, thermic Typic Ustochrept) with parts of the area above the two bottom terraces on Port silt loam (fine-silty, mixed, thermic Cumulic Haplustoll). The nitrogen rate experiment was conducted on the Port silt loam on a floodplain at the base of the slope containing the terrace area.

The nitrogen rate experiment consisted of four nitrogen treatments completely randomized within each of four blocks. Plots measured 15.2 by 6.1 meters each. On October 9, 1979, this experimental site was laid out and the soil of each replication sampled as for the east farm method-of-placement experiment. Fertilizer treatments (Table III) were applied. In the same manner as for the east farm phosphorus method-of-placement experiment, forage samples were taken in March of 1980 from each replication. On June 16, 1980, grain was harvested, yield

TABLE III

SOIL TYPE AND FERTILIZER TREATMENTS, NITROGEN RATE EXPERIMENT, CORDELL, 1979-1980

Location	Soil Type	Treatment Number	Treatments N-P-K	Fertilizer Material
			-kg/ha-	
Cordell West Farm	Port silt loam (Cumulic Haplustoll)	1	0-0-0	Ammonium nitrate (34-0-0)
		2	25-0-0	
		3	50-0-0	
		4	100-0-0	

determined, and grain samples taken as previously described for the east farm replicated experiment.

The nitrogen terraced area consisted of eight terraces, plus the level areas above each terrace. On October 9, 1979, an experiment was laid out consisting of 4.9 m wide strips of nitrogen fertilizer alternating with check strips of the same width. All strips on this experiment ran up the slope, perpendicular to the contours of the terraces and level areas between terraces. Nitrogen was applied as ammonium nitrate at either of two rates. A total of four fertilized strips and five check strips comprised the experiment. On October 9, 1979, soil from the first four easterly-most check strips was sampled. Thirteen to fifteen cores of soil were taken from and composited for the level area above each terrace in these strips. Fertilizer in treated strips was broadcast and disced in. No forage samples were taken. On June 16 and June 18, 1980, grain was harvested, yield determined, and grain samples taken from a 15.2 m wide section of the strip marked off in the middle of each level area. Grain from the four westerly most check strips and the four treated strips was weighed and sampled. The eastern most check strip was not harvested for data because it had been used during the growing season as a road and the wheat in this strip had sustained substantial damage inflicted by vehicle traffic. For simplicity, the soil-sampled and harvested plots will be denoted by the number of the terrace below them; thus, "in strip one" a plot "on the level above terrace one" would be called only "strip one, terrace one," etc. Terraces are numbered starting at the bottom of the slope.

Laboratory Experiments

Soil Procedures

Soil samples were thoroughly mixed and part of each sample bagged and sent to the Oklahoma State University's Plant, Soil, and Water Testing Laboratory (to be referred to as the OSU Soil Testing Lab) for analysis for pH, NO_3-N, P, and K. The Laboratory's standard procedures were used. The pH procedure involves measuring the pH of a 1:1 soil: water suspension on a pH meter. Testing for nitrate nitrogen involves extracting 1 part of soil with 2.5 parts of calcium sulfate extractant and testing the resulting suspension with a nitrate electrode. Phosphorus is determined by use of the Bray P-1 method using a 1:20 soil: solution ratio. The filtrate of a soil-ammonium acetate suspension was read for potassium on an atomic absorption spectrophotometer.

The remainder of each soil sample was dried for approximately 36 hours at 60^{o}C and then ground. Twenty samples testing very low in P were then selected. These soils were analyzed for NO_3-N and NH_4-N. These soils were further tested for P by the Bray P-1 method (Bray and Kurtz, 1945) and the method proposed by Mehlich (Mehlich, 1978). Three soil:extractant ratios were used for each test: 1:20, 1:50, and 1:100.

Available phosphorus on the twenty selected soils was first measured by the Bray P-1 method using 0.03 N NH_4F in 0.025 N HCl (Bray and Kurtz, 1945), at a soil:solution ratio of 1:20. One gram of soil was measured into a 50 ml erlenmeyer flask and 20 ml of extracting solution added. Extracting solution consisted of 41.7 ml of concentrated HCl and 22.22 g of NH_4F added to 5 liters of deionized water and dissolved, the total then being brought to a volume of 20 liters. The soil-extractant solution was then shaken for 5 minutes and immediately filtered through Whatman #2 filter paper. A 5 ml aliquot of each sample and standard was placed in a 100 ml beaker and 10 ml of a 1.0 percent by weight solution of boric acid in water added to each beaker. Five ml of an absorbic acid solution was also added. For this solution 1.06 g of L-ascorbic acid was mixed with 200 ml of an ammonium molydate-antimony potassium tartrate solution. The tartrate solution was prepared by dissolving 12 g of ammonium molybdate $(NH_4)_6MO_7O_{24}$ in 250 ml of deionized water; dissolving 0.291 g of antimony potassium tartrate in 100 ml of deionized water; mixing 148 ml of concentrated H_2SO_4 in 1000 ml of deionized water; then mixing these three solutions and bringing the mix to a final volume of 2000 ml with deionized water. This tartrate solution was stored in an opaque container. The ascorbic acid sultuion was prepared daily, using the tartrate solution. After one hour each sample, standard, and blank was read on a Bausch and Lomb Spectronic 20 colorimeter coupled to a Fisher concentration computer. The Spectronic 20 was also equipped with a vacuum apparatus which drew the sample through tubing into the photocell and then out to a waste reservoir. A 1000 ppm P stock solution was used to make a 20 ppm P stock solution from which 0.8, 1.6, 2.4, 3.2, 4.0, and 4.8 ppm P/g soil standards were prepared. The soil:solution ratio for the Bray test was changed to 1:50 and then to 1:100 and these same soils tested, using new standards whose concentrations covered the range of concentrations encountered in these more dilute samples.

These twenty soils were also tested for P by use of the Mehlich extractant at each of the three soil:extractant ratios. Mehlich's extractant (0.2 N NH_4Cl-0.2 N HOAc-0.015 N NH_4F-0.012 N HCl, pH approximately 2.5, Mehlich, 1978) was prepared by dissolving 5.6 g of NH_4F in 5 liters of deionized water, adding 10 ml of concentrated HCl and 115 ml of glacial acetic acid, and bringing the mix to 10 liters total volume with deionized water. The same procedure for the phosphorus test was followed as for the Bray extractant. The same reagents in the same aliquot sizes constituted the test solution, the phosphorus concentration of which was determined on a Spectronic 20 colorimeter. Standard concentration ranges for each soil: solution ratio were the same as for the Bray test.

In all soil procedures, samples were run in duplicate. When necessary, samples were re-run until two readings were obtained which agreed to within 5 percent of their magnitude. These two readings were then averaged. Readings in ppm P or ppm N/g soil were directly converted to kilograms of nutrient per hectare.

Plant Procedures

Forage and grain samples were dried for approximately 12 hours and ground to pass through 200 mesh sieve. Samples were tested for total N, P, and K contents. All samples were thoroughly mixed prior to being weighed out for acid digestion.

Total nitrogen content of both forage and grain samples was determined by a modified microkjeldahl procedure. Samples were dried for 2 to 4 hours at 60°C and cooled. On filter paper, 250 $\pm$ 3 mg of sample was weighed out and the weight recorded. The filter paper was then folded and placed in the bottom of a digestion tube, and 2.1 g of catalyst added. Next was added 7 ml of concentrated H_2SO_4 and then 1 ml of 30 percent H_2O_2. The tube was placed in a block digestor preheated to 420°C, and digested for 1 hour. The sample was then removed from the block, cooled for 10 minutes, and diluted with approximately 25 ml of deionized water, which prevented precipitation of salts in the tube. The tube contents were then quantitatively transferred to a 100 ml microkjeldahl flask. Any tube in which salt crystals had formed was heated over a bunsen burner and the contents transferred. The tube was then rinsed two to four times. All rinsings were added to the flask, and approximately 25 ml of 10 N NaOH slowly added prior to steam distillation. Distillation was then carried out until approximately 25 ml of the flask contents had been carried over into a 50 ml erlenmeyer catch flask containing 5 ml of a boric acid indicator solution. The blue-green contents of the catch flask were then titrated with a standardized 0.0100 N HCl to a light pink end-point, the volume of acid recorded, and the percent of N of the plant sampled calculated.

Total phosphorus content of both forage and grain samples was determined by digesting samples with nitric and perchloric acids and then testing the resulting solutions colorimetrically. Dried sample material (200 ± 3 mg) weight recorded, was placed in a calibrated 50 ml test tube. Fifty ml of concentrated nitric acid and then 2 ml of concentrated perchloric acid was added. The tube was placed in a block digestor programmed to heat at 100°C for 30 minutes, then at 175°C for 1 hour, and then at 265°C for approximately 2 hours or until 0.5 ml of digested sample remained in the tube. The tube, once cooled, was diluted to 50 ml with deionized water. A 5 ml aliquot was pipetted into a 200 ml tall-form beaker, and diluted to 50 ml with deionized water. Five ml of a 2 percent hydrazine sulfate solution was next added and the beaker then placed on a hot plate until the contents came to a boil.

The contents were allowed to cool and then brought to a final volume of 100 ml. The Bausch and Lomb Spectronic 20, connected to a concentration computer and a vacuum apparatus, was used to read the phosphorus concentrations of blanks, standards, and samples. A 1000 ppm P stock solution was used to make a 25 ppm P solution from which standards were prepared.

Total potassium content of both forage and grain samples was determined by reading the solution resulting from nitricperchloric digestion on a Perkin-Elmer 403 Atomic Absorption Spectrophotometer. An acetylene air flame was used.

As for all soil procedures, all forage and grain samples were run in duplicate for plant procedures. When necessary, samples were re-run until two readings were obtained which agreed to within 5 percent of their magnitude. Duplicate readings were averaged.

Method of Data Evaluation

Statistical manipulations of data were accomplished by computer. Programs of the SAS or Statistical Analysis System, (Helwig and Council, 1979) were utilized. Melsted and Peck's article (Melsted and Peck, 1977) was used as a guide for use of the Mitscherlich-Bray growth function in evaluation of the efficiency of various levels of fertilizer and soil phosphorus.

CHAPTER IV

RESULTS AND DISCUSSION

Soil Sampling of a Terraced Field

Number of Samples Required

The number of observations was calculated using Stein's procedure. The formula is $N = \frac{t_1^2 s^2}{d^2}$ (Steel and Torrie, 1960). Here N stands for the number of observations required, t_1 is the tabulated t value for the desired confidence level and the degrees of freedom of the sample, s is the standard deviation of the sample, and d is the half-width of the desired confidence interval. The procedure is to take a sample (in this case soil pH, N, P, and K values from the west terraced field - Table IV). The variance over the entire field of each of these four variables. was estimated. Then the total number of needed observations was calculated.

Four other methods were used for calculating the total number of observations, N. The area was divided by four different methods; by terrace, by strip, and by SW-NE or SE-NW diagonal arrangement of plots. All four soil sampled strips and all eight terraces were used. Each terrace, strip, or diagonal was counted as an individual division for which s^2, t^2, d^2 and N was obtained. A total N was obtained over all divisions for each method of division. Thus four total N's were obtained. These total N's were compared to the N previously determined

TABLE IV

INITIAL SOIL TEST PH, N, P, AND K VALUES, CORDELL, OKLAHOMA, WEST TERRACES, 1979-1980

Terrace Number	pH				N				P				K			
	Strip Number															
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
					kg/ha											
1	7.2	7.0	7.2	7.0	56	80	81	108	118	132	152	156	858	939	959	1005
2	8.0	7.8	8.0	7.9	108	99	86	105	67	78	85	95	595	666	710	753
3	8.2	8.2	8.3	8.3	96	87	96	105	3	4	8	12	522	547	540	534
4	8.2	8.3	8.2	8.3	146	66	83	93	40	34	34	27	681	626	631	561
5	8.2	8.3	8.3	8.3	92	115	113	125	40	60	40	45	654	698	666	644
6	8.4	8.2	8.4	8.3	91	119	105	148	38	40	11	11	713	671	624	585
7	8.4	8.4	8.2	8.3	90	111	110	156	3	6	9	4	513	492	478	493
8	8.3	8.2	8.3	8.1	85	99	99	137	60	57	43	31	455	452	461	445

over the entire field. The 0.10 significance level was used to determine $N_{0.10}$.

Tables V through VIII contain the number of samples data. In all cases except for that of pH, the least number of samples was required for a representative total sample when the entire field was sampled undivided. The objective of this study was to ascertain how to best subdivide this entire area so as to sample in a manner more accurately accounting for variations in soil properties. Results indicate that in all cases except for that of nitrogen, the method of field division requiring the least number of samples was that according to terrace. As an example, in Table VIII, at the 0.10 significance level, 63 samples taken over the entire field comprise a representative sample; the totals for the four methods of division range from 69 to 351 samples and the method of division requiring the least number (69) is that according to terrace. It may be of interest here to note that when this terraced experiment was initiated, 13 to 15 samples were taken per soil-sampled plot, for an average of 14 samples per each of 32 plots or a total of 448 samples. Current recommendations in Oklahoma instruct the agricultural producer to composite 20 samples randomly selected over an area receiving the same management practices, in this case the west farm terraces plus the surrounding level field which contains the nitrogen rate experiment. In most cases these experimental results indicate that more than the recommended 20 samples need to be taken on the terraced field alone.

Although these results indicate that soil samples for nitrogen would number the least if the entire field was sampled by strips, data in the "Variation in Soil Properties" section following shows, for the

TABLE V

MEANS, RANGES, AND VARIANCES OF SOIL PH VALUES AND $N_{0.10}$ VALUES, BY FIELD DIVISION, CORDELL, OKLAHOMA, WEST TERRACE EXPERIMENT, 1979-1980

Sample Identity	pH $\bar{x}$	pH Range	s^2	*$N_{0.10}$
Entire Field	8.1	7.0-8.4	0.1633	3.0
Terrace 1	7.1	7.0-7.2	0.0130	0.6
Terrace 2	7.9	7.8-8.0	0.0092	0.3
Terrace 3	8.2	8.2-8.3	0.0033	0.1
Terrace 4	8.2	8.2-8.3	0.0033	0.1
Terrace 5	8.3	8.2-8.3	0.0025	0.1
Terrace 6	8.3	8.2-8.4	0.0092	0.3
Terrace 7	8.3	8.2-8.4	0.0092	0.3
Terrace 8	8.2	8.1-8.3	0.0093	0.3
TOTAL				2.1
Strip 1	8.1	7.2-8.4	0.1527	3.3
Strip 2	8.0	7.0-8.4	0.2114	4.7
Strip 3	8.1	7.2-8.4	0.1498	3.3
Strip 4	8.1	7.0-8.3	0.2055	4.5
TOTAL				15.8
SW-NE Diagonals				
Diagonal 1	8.4	8.3-8.4	0.0033	0.1
Diagonal 2	8.3	8.2-8.4	0.0067	0.2
Diagonal 3	8.3	8.2-8.4	0.0067	0.2
Diagonal 4	8.2	7.9-8.3	0.0358	1.2
Diagonal 5	7.8	7.0-8.2	0.3300	11.9
TOTAL				13.6
SE-NW Diagonals				
Diagonal 1	8.2	8.1-8.2	0.0250	0.1
Diagonal 2	8.3	8.2-8.4	0.0067	0.2
Diagonal 3	8.3	8.2-8.3	0.0025	0.1
Diagonal 4	8.2	8.0-8.3	0.0158	0.5
Diagonal 5	7.9	7.2-8.3	0.2733	9.7
TOTAL				10.6

*$N_{0.10}$ is the number of observations required to sample this field for an estimate of the true mean soil pH value. Confidence level = 0.90.

TABLE VI

MEANS, RANGES, AND VARIANCES OF SOIL NITROGEN CONTENTS AND $N_{0.10}$ VALUES, BY FIELD DIVISION, CORDELL, OKLAHOMA, WEST TERRACE EXPERIMENT, 1979-1980

Sample Identity	N $\bar{x}$	N Range	s^2	*$N_{0.10}$
	kg/ha	kg/ha		
Entire Field	103	56-156	446	54
Terrace 1	82	56-108	395	150
Terrace 2	100	86-108	82	21
Terrace 3	96	87-105	48	13
Terrace 4	96	66-146	1052	278
Terrace 5	112	92-125	178	36
Terrace 6	115	91-148	529	98
Terrace 7	116	90-156	696	127
Terrace 8	105	85-137	440	100
TOTAL				823
Strip 1	95	56-146	560	99
Strip 2	96	66-119	301	52
Strip 3	96	81-113	137	24
Strip 4	122	93-156	465	50
TOTAL				225
SW-NE Diagonals				
Diagonal 1	106	85-125	249	54
Diagonal 2	104	90-119	187	43
Diagonal 3	99	83-115	189	48
Diagonal 4	90	66-105	253	78
Diagonal 5	106	86-146	687	150
TOTAL				373
SE-NW Diagonals				
Diagonal 1	114	92-137	319	59
Diagonal 2	130	105-156	514	75
Diagonal 3	105	66-148	1038	230
Diagonal 4	101	83-125	333	181
Diagonal 5	86	56-99	361	121
TOTAL				566

*$N_{0.10}$ is the number of observations required to sample this field for an estimate of the true mean soil N content. Confidence level = 0.90.

TABLE VII

MEANS, RANGES, AND VARIANCES OF AVAILABLE SOIL PHOSPHORUS CONTENTS AND $N_{0.10}$ VALUES, BY FIELD DIVISION, CORDELL, OKLAHOMA, WEST TERRACE EXPERIMENT, 1979-1980

Sample Identity	P $\bar{x}$	P Range	s^2	$*N_{0.10}$
	kg/ha			
Entire Field	48	3-156	1673	934
Terrace 1	139	118-156	286	36
Terrace 2	82	67-95	123	46
Terrace 3	6	3-12	15	57
Terrace 4	32	27-37	390	900
Terrace 5	46	37-60	96	115
Terrace 6	25	11-33	206	863
Terrace 7	5	3-9	6	413
Terrace 8	48	31-60	162	176
TOTAL				2606
Strip 1	46	3-118	1231	956
Strip 2	52	4-132	1555	958
Strip 3	48	8-152	2174	1535
Strip 4	48	4-156	2434	1718
TOTAL				5167
SW-NE Diagonals				
Diagonal 1	30	6-60	624	1661
Diagonal 2	27	3-40	249	854
Diagonal 3	36	12-60	348	662
Diagonal 4	44	8-95	1216	1601
Diagonal 5	71	4-156	3855	1920
TOTAL				6698
SE-NW Diagonals				
Diagonal 1	29	9-37	159	482
Diagonal 2	28	4-60	587	1819
Diagonal 3	22	3-40	843	4228
Diagonal 4	38	4-67	607	1070
Diagonal 5	58	8-118	2218	1654
TOTAL				9253

$*N_{0.10}$ is the number of observations required to sample this field for an estimate of the true mean available soil P content. Confidence level = 0.90.

TABLE VIII

MEANS, RANGES AND VARIANCES OF SOIL POTASSIUM CONTENTS AND $N_{0.10}$ VALUES, BY FIELD DIVISION, CORDELL, OKLAHOMA, WEST TERRACE EXPERIMENT, 1979-1980

Sample Identity	K $\bar{x}$	K Range	s^2	$^*N_{0.10}$
	kg/ha	kg/ha		
Entire Field	631	445-1005	19585	63
Terrace 1	940	858-1005	3353	9
Terrace 2	681	595-753	4058	22
Terrace 3	535	522-547	97	1
Terrace 4	625	561-681	2156	14
Terrace 5	665	644-698	486	3
Terrace 6	648	585-713	2799	2
Terrace 7	494	478-513	183	2
Terrace 8	454	445-461	43	1
TOTAL				69
Strip 1	624	455-858	15195	63
Strip 2	636	452-939	20421	63
Strip 3	634	461-959	22360	90
Strip 4	627	445-1005	28660	117
TOTAL				351
SW-NE Diagonals				
Diagonal 1	553	455-644	7952	64
Diagonal 2	603	513-671	5503	38
Diagonal 3	644	534-713	5935	35
Diagonal 4	643	540-753	6867	41
Diagonal 5	736	547-1005	33261	152
TOTAL				330
SE-NE Diagonals				
Diagonal 1	562	445-671	12239	96
Diagonal 2	624	493-698	7708	49
Diagonal 3	600	522-666	3534	24
Diagonal 4	604	542-644	1693	12
Diagonal 5	656	540-858	18862	109
TOTAL				290

$^*N_{0.10}$ is the number of observations required to sample this field for an estimate of the true mean soil K content. Confidence level = 0.90.

most part, no significant differences in nitrogen values from strip to strip, thus eliminating sampling according to strip as a possibility worth pursuing.

Variations in Soil Properties

Data in Table IX indicate the results of Duncan's multiple range tests designed to reveal significant differences in pH and in N, P, and K contents of soil in different terraces, strips, and diagonals. An additional soil property is included in these calculations, the soil phosphorus efficiency factor c_1 calculated from the Mitscherlich-Bray equation:

$$\log (A-y) = \log A-c_1 b$$ (Melsted and Peck, 1977)

where A is the maximum yield obtainable, y is the actual yield obtained on the given plot, b is the State Lab soil test phosphorus value for that plot, and c_1 is the efficiency factor for that soil phosphorus. In this case, A was considered to be the maximum yield of grain obtained on any plot in the entire field (3071 kg/ha, strip 4, terrace 2), and this same value was used for all plots. A plot consisted of any terrace-strip combination, as in "the plot on terrace 3, strip 2." Since grain was not harvested in strip 1, c_1 data was not calculated for strip 1. Table X lists the grain yield and c_1 data from this terraced field.

Significant differences were found between means of c_1 values over terraces. These differences reflect the results for P values over terraces. The mean of the bottom terrace P values was significantly higher than that of any other terrace. Similarly, the two bottom terraces were grouped in the lowest soil P efficiency (c_1) group. This

TABLE IX

MEANS AND SIGNIFICANT DIFFERENCES BETWEEN MEANS OF SOIL PH, N, P, AND K CONTENTS OVER DIVISIONS OF A TERRACED FIELD, CORDELL, OKLAHOMA, 1979

Method of Subdivision	Means of Given Soil Property by Subdivision				
	pH	N	P	K	Cl
		kg/ha	kg/ha	kg/ha	
Terraces					
Terrace 1	7.1	81	139 a	940	0.0071 c
Terrace 2	7.9	99	81 b	681	0.0207 c
Terrace 3	8.2	96	7 e	536	0.1094 b
Terrace 4	8.2	99	33 cd	625	0.0071 c
Terrace 5	8.3	114	46 c	666	0.0054 c
Terrace 6	8.3	116	24 d	648	0.0100 c
Terrace 7	8.3	116	6 e	494	0.1627 a
Terrace 8	8.2	105	48 c	453	0.0162 c
Strips					
Strip 1	8.1	95 b	46	624	--
Strip 2	8.0	99 b	51	636	0.0473
Strip 3	8.1	97 b	48	634	0.0316
Strip 4	8.1	123 a	48	627	0.0481

TABLE IX (Continued)

Subdivision	Means of Given Soil Property by Subdivision				
	pH	N	P	K	cl
		——— kg/ha ———			
SW-NE Diagonals					
Diagonal 1	7.5 c	94	100	767	0.1214 a
Diagonal 2	7.7 bc	88	78	740	0.0373 c
Diagonal 3	7.8 bc	105	72	722	0.0633 b
Diagonal 4	8.2 ab	90	43	643	0.0079 d
Diagonal 5	8.3 ab	99	36	644	0.0325 c
Diagonal 6	8.3 ab	104	27	603	0.0419 cb
Diagonal 7	8.4 a	109	31	554	0.0475 c
Diagonal 8	8.2 ab	119	26	505	0.0089 d
Diagonal 9	8.3 ab	127	24	477	
SE-NW Diagonals					
Diagonal 1	7.6	93 ab	124 a	856 a	0.0075 d
Diagonal 2	7.8	80 b	77 ab	728 ab	0.1009 a
Diagonal 3	7.9	86 b	58 b	656 ab	0.0389 c
Diagonal 4	8.2	104 ab	38 b	604 b	0.0768 b
Diagonal 5	8.3	106 ab	22 b	600 b	0.0086 d
Diagonal 6	8.3	130 a	28 b	624 b	0.0528 c
Diagonal 7	8.2	114 ab	29 b	562 b	0.0408 c
Diagonal 8	8.4	100 ab	29 b	556 b	0.0390 c
Diagonal 9	8.3	94 ab	30 b	483 b	0.0153 d

Means within columns with the same letter are not significantly different at the 0.05 significance level as determined by the Duncan's Multiple Range test.

TABLE X

GRAIN YIELD AND PHOSPHORUS C_1 VALUES FOR WEST TERRACE EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Terrace Number	Grain Yield			Phosphorus* C_1		
	Strip Number					
	2	3	4	2	3	4
	kg/ha					
1	2797	2739	2514	0.0089	0.0071	0.0053
2	2846	3013	3071	0.0163	0.0224	0.0235
3	2269	2426	2719	0.1459	0.0967	0.0857
4	959	1076	1261	0.0054	0.0063	0.0096
5	1536	949	1340	0.0056	0.0045	0.0062
6	215	313	939	0.0096	0.0046	0.0158
7	2680	2475	2670	0.1791	0.0887	0.2202
8	1800	2651	2142	0.0075	0.0226	0.0185

*The phosphorus C_1 value is a measure of the efficiency of a given level of soil phosphorus (b), calculated in terms of yield obtained (y) compared to maximum possible yield (A) by the Mitscherlich - Bray equation, $\log(A-y) = \log A - C_1 b$.

follows from the relationship between a soil test P value and a soil P efficiency factor: the higher the soil test P value supporting a given yield, the lower the soil P efficiency factor or c_1. In other words, if a high soil test P level supports the yield which a low soil test P level in different circumstances does, the higher soil test P level is less efficient and has a lower c_1 value. Also, results show that terraces 3 and 7 have significantly lower soil test P values and significantly higher c_1 values than the other terraces. Soil test P values on terraces 3, 6, and 7 are the values suspect as indicating areas exhibiting the phosphorus-extraction problems on high-pH soils, and their c_1 values suspect as being thus artifically higher because of the erroneous soil test P data from which they are calculated.

According to the number of samples, N data, the most variation over a terraced field is encountered in soil P content and the least in pH value. Sampling by terrace proves from Tables V to VIII to require the least work while providing the most discrimination between areas varying in soil properties. This is presumably because the nature of a sloping field is to have soil properties gradually changing with elevation and thus terraces divide these soil property gradients into packages which can be separately sampled.

The data is not adequate to make a prediction concerning which terraces to sample or how may terraces to combine into one sample. In some cases the soil in a particular terrace is known to be high in pH and prone to give erroneously low soil test P results. When a soil testing service has developed a calibration for a P extractant designed specifically for testing high pH soils correctly, this terrace should be sampled separately from the others and the sample sent to that soil testing service. The terraces at the footslope of this field, terraces 1 and 2, were on a flatter slope than were the rest. These two terraces also contained inclusions of the soil series of the surrounding level field on which the nitrogen rate experiment was conducted. For these two reasons terraces 1 and 2 possessed properties grading between those of the terraced field and those of the level field below. The data showed these two terraces to be significantly different from the rest. A recommendation would be to separately sample the bottom terraces of a terraced field. Another option would be to just sample the level field and the terraced field separately, not discriminating between terraces on the terraced field except to start sampling in those terraces safely above the footslope (where the soil properties reflect to an extent the nature of the level ground below, not the nature of the terraced field).

Response to Nitrogen Fertilizer

Initial soil test values as determined by the state lab for the nitrogen rate experiment on the west farm are reported in Table XI. The nitrogen values are all above the 90 kg/ha or 80 lb/A nitrogen level required to reach the yearly yield goal on this field of 2688 kg grain/A or 40 bu grain/A. Soil phosphorus and potassium levels are all high and above adequate (these recommendations from O.S.U. Fact Sheet 2225). Various parameters measuring crop response to the three rates of nitrogen fertilizer were analyzed to see if a crop response to nitrogen fertilizer would indeed not be obtained if the current nitrogen calibration on which Fact Sheet 2225 is based is accurate. Grain yield and grain and forage contents of N, P, and K from this experimental site are reported in Table XII. Data indicate that no significant response to

TABLE XI

INITIAL SOIL TEST VALUES - WEST NITROGEN RATE EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Replication Number	pH	N	P	K
		kg/ha		
1	7.1	134	111	1120
2	6.9	109	128	1109
3	7.2	122	90	1049
4	7.1	99	120	972

TABLE XII

MEANS OF GRAIN YIELD, AND GRAIN AND FORAGE CONTENTS OF N, P, AND K, NITROGEN FERTILIZER RATE EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Treatment	Grain				Forage		
N-P-K	Yield	N	P	K	N	P	K
	kg/ha	%					
0-0-0	2910	2.47	0.35	0.50	5.25	0.41	4.12
25-0-0	3110	2.50	0.41	0.52	5.24	0.41	4.21
50-0-0	3170	2.50	0.41	0.52	5.03	0.42	4.16
100-0-0	3190	2.64	0.43	0.59	5.33	0.42	4.15
LSD (0.05)	419	0.16	0.07	0.07	0.47	0.05	0.28
PR > F	0.4596	0.1476	0.1447	0.0689	0.5479	0.8945	0.9115

added nitrogen did occur. Neither the yield nor the nitrogen nutrition of the plant as measured by grain and forage N contents was significantly affected by the addition of fertilizer. This was according to the prediction given in recommendations from the O.S.U. lab and thus serves to support the reliability of the calibration for nitrogen on wheat.

Percent Sufficiency of Phosphorus

The percent sufficiency of soil phosphorus is determined on the basis of grain yields produced. Grain yield is determined on a test plot adequate in every nutrient but phosphorus. Maximum possible yield is obtained on an adjacent plot having adequate levels of every nutrient, including phosphorus. A ratio of grain yield to maximum possible grain yield is calculated.

In each replication of the east farm P methods experiment, a ratio was calculated of grain yield from the 80-0-0 treated plot over the grain yield from the 80-40-0 (broadcast and disced phosphorus) treated plot. The 80-40-0 treated plot was chosen over the 80-80-0 treated plot so as to make comparisons to the 80-40-0 treated east terraces possible. The ratio was multiplied by 100 to give percent. The initial soil test phosphorus level of the 80-0-0 treated plot was thus given a percent sufficiency value.

The same calculations were made for the west farm terrace experiment. Average grain yield was determined for each terrace. Yield from the highest-yielding terrace, terrace 2, was considered the maximum possible yield in percent calculations for each of the eight terraces.

Percent sufficiency data is reported in Table XIII. Soil of the

TABLE XIII

PERCENT SUFFICIENCIES OF VARIOUS LEVELS OF SOIL PHOSPHORUS AS INDICATED BY FACT SHEET 2225 AND CALCULATED FROM DATA FROM CORDELL, OKLAHOMA, 1979-1980

Location	Grain Yield	State Lab Soil Test N	State Lab Soil Test P	Percent Sufficiencies Calculated	Percent Sufficiencies Fact Sheet 2225
	kg/ha				
Fact Sheet 2225		0	11		25
Calibrations		11	22		45
		22	45		80
		45	73		90
		73			100
regression equation: $Y = 10.8 + 2.5X - 0.018X^2$					
East Farm P					
Method Area					
Rep 1	336	46	0	31	0
Rep 2	988	32	17	91	45
Rep 3	1082	28	28	100	80
Rep 4	517	30	0	48	0
regression equation: $Y = 39.5 + 4.4X - 0.079X^2$					
West Farm					
Terraces					
Terrace 1	2675	81	147	90	100
Terrace 2	2970	99	86	100	100
Terrace 3	2466	96	8	83	25
Terrace 4	1095	97	31	37	80
Terrace 5	1270	111	48	43	90
Terrace 6	484	116	20	16	45
Terrace 7	2601	116	7	88	25
Terrace 8	2191	105	44	74	80
regression equation: $Y = 26.0 + 2.3X - 0.01X^2$					

east farm was deficient in nitrogen as well as in phosphorus. Thus N-treated plots were required for comparison to N- and P-treated plots for these calculations. No N-treated plots were available for comparison to N- and P- treated plots on the terraced field. For this reason, data is reported for the east farm P methods experiment only. Soil nitrogen levels on the west terraced experiment were adequate. Thus, this area was considered to be N-treated. Soil P covered a wide range of values. Percent sufficiency of each level of soil phosphorus was calculated and compared to the percent sufficiencies predicted by Fact Sheet 2225.

Plots of the data in Table XIII are contained in Figures 1 through 3. Fact Sheet 2225 data (Figure 1) follows a curve described by the regression equation $Y = 10.8 + 2.5X - 0.018X^2$. The law of diminishing returns of grain yield response to inputs of soil P is observed.

The same diminishing returns of grain yield per unit input of soil P are shown by the plot of east farm P methods experiment data (Figure 2). The regression equation is $Y = 39.5 + 4.4X = 0.079X^2$. This curve rises sharply and peaks at a maximum percent sifficiency much sooner (at a lower soil P value) than does the curve in Figure 1. This can be explained by the nature of the soils in the east P methods experiment. In the past, these soils had been known to test very low in P while supporting crop yields normally sustained by higher soil P levels. The problem is one involving the Bray P-1 soil test procedure, as previously discussed. Soil test P values of 0 kg/ha for replications 1 and 4 are graphic examples of erroneously low soil test P levels on high-pH calcareous soils. With higher, more nearly representative soil test P values, this curve would have spread further to the right than it did.

In Figure 3, a curve for soil P percent sufficiency is obtained

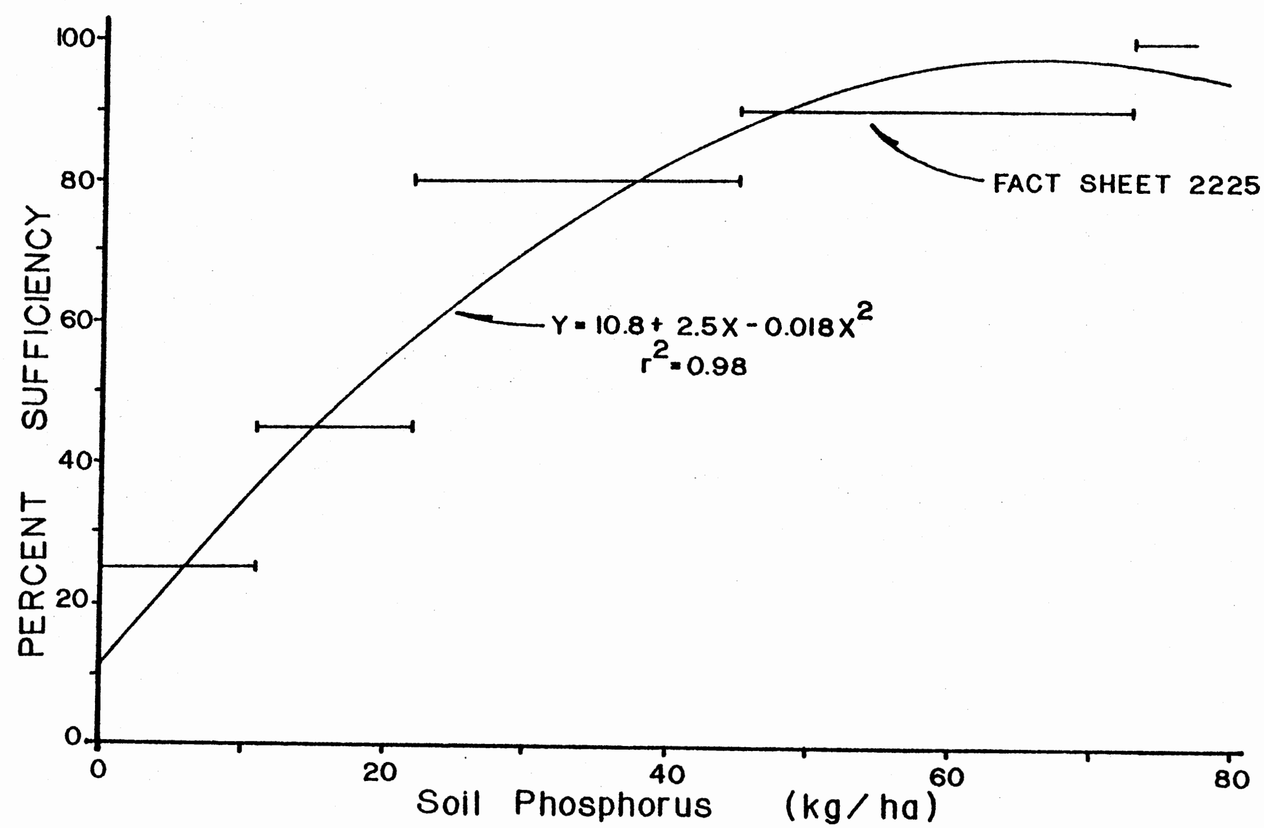

Figure 1. Soil Phosphorus Versus Percent Sufficiencies, Fact Sheet 2225 data.

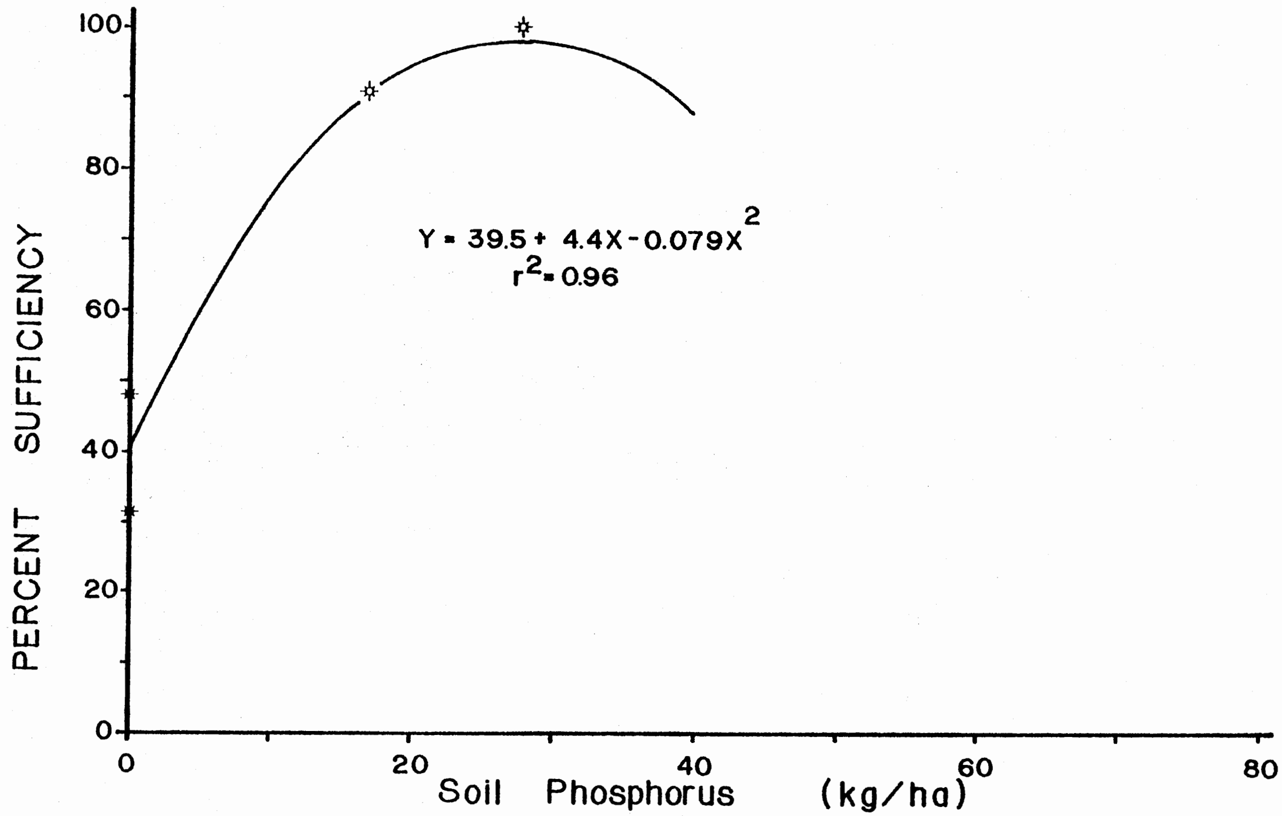

Figure 2. Soil Phosphorus Versus Percent Sufficiencies, Cordell P Methods Experiment, 1979-1980.

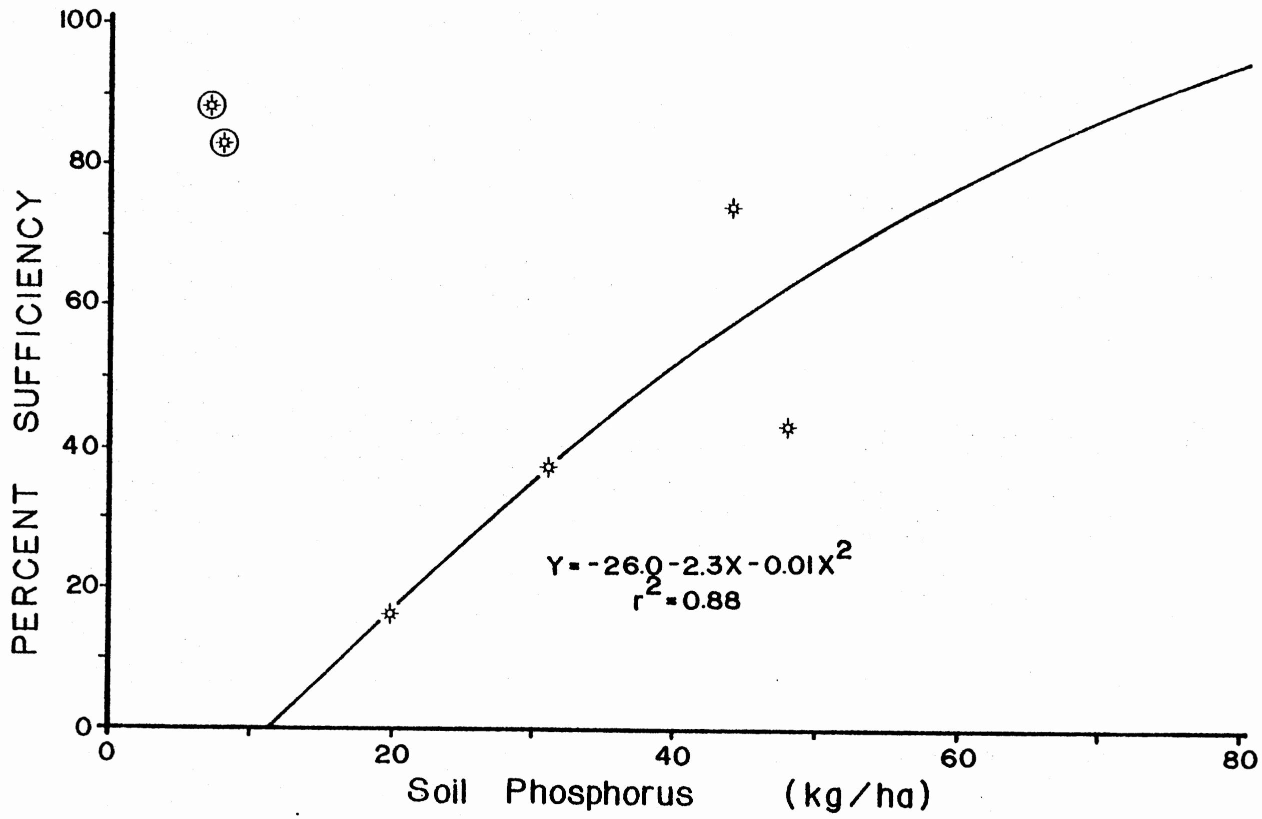

Figure 3. Soil Phosphorus Versus Percent Sufficiencies, Cordell West Terraces, 1979-1980.

from the regression equation $Y = 26.0 + 2.3X - 0.01 X^2$. Again this curve follows the same shape as does the curve of 2225 data. This regression used six data points, the data points for terraces 3 and 7 (upper left-hand corner) having been omitted. These terraces had already been shown in the "Soil Sampling of a Terraced Field" section to have significantly lower soil P values. The problem with the Bray P-1 soil test procedure was displayed also on these terraces. To include terraces 3 and 7, this experiments' regression equation would be $Y = 62.9 - 0.2X + 0.003X^2$, $r^2 = 0.19$. This slightly concave horizontal line would not fit the data adequately.

The two experimental curves resemble the 2225 curve in slope and diminishing returns behavior. Problems arise with the soil test P data on which the curves are based. With correct soil test P data, these curves would more nearly imitate that of the Fact Sheet 2225 data, supporting the reliability of the Oklahoma soil test P calibration.

Placement of Phosphorus Fertilizer

Initial soil test values for both experiments on the east farm are recorded in Table XIV. Grain yield and grain and forage N, P, and K content data from all plots on the east farm methods-of-placement of fertilizer phosphorus experiment are recorded in Table XV.

Data in Table XV indicate highly significant responses of grain yield, grain nitrogen content, and grain phosphorus content to treatments, although there is no indication of which component of treatment rate, or method of placement produced the response. Duncan's multiple range tests, the results of which are reported in Table XVI, indicate responses to nitrogen fertilizer, not to phosphorus fertilizer rates or

TABLE XIV

INITIAL SOIL TEST VALUES, EAST PHOSPHORUS METHODS-OF-PLACEMENT EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	pH	NO_3-N	P	K
		kg/ha		
Phosphorus Methods Area				
Rep 1	8.3	46	0	394
Rep 2	8.4	32	17	475
Rep 3	8.3	28	28	512
Rep 4	8.4	36	0	503

TABLE XV

MEANS OF GRAIN YIELD AND GRAIN AND FORAGE CONTENTS OF N, P, AND K, PHOSPHORUS METHODS-OF-PLACEMENT EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Treatment		Grain			Forage		
N-P-K	Yield	N	P	K	N	P	K
	kg/ha	%					
0-0-0	740	2.03	0.43	0.42	--	--	--
80-0-0	1050	2.61	0.31	0.41	4.28	0.40	3.54
P broadcast and disced in							
80-20-0	1420	2.53	0.34	0.40	3.97	0.39	3.20
80-40-0	1450	2.52	0.35	0.41	3.57	0.35	2.79
80-80-0	1490	2.38	0.34	0.40	4.25	0.46	3.33
P banded with the seed							
(80+6)-20-0	1180	2.48	0.30	0.39	4.32	0.42	3.54
(80+12)-40-0	1500	2.48	0.31	0.40	4.42	0.43	3.57
(80+24)-80-0	1520	2.51	0.33	0.41	4.30	0.44	3.55
LSD (0.05)	404	0.21	0.04	0.04	1.28	0.13	0.92
PR > F	0.0048**	0.0006**	0.0002**	0.8703	0.08200	0.6293	0.5427

*Means significantly different at the 0.05 significance level.
**Means significantly different at the 0.01 significance level.

TABLE XVI

SIGNIFICANT DIFFERENCES IN MEANS OF SELECTED CROP RESPONSE PARAMETERS AS DETERMINED BY DUNCAN'S MULTIPLE RANGE TEST, EAST FARM P METHODS EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Treatment	Grain Yield	Means of Given Crop Response Parameter	
		Grain N	Grain P
	kg/ha	%	
0-0-0	740 c	2.03 b	0.43 a
80-0-0	1050 bc	2.61 a	0.31 b
P broadcast and disced in			
80-20-0	1420 ab	2.53 a	0.34 b
80-40-0	1450 ab	2.52 a	0.35 b
80-80-0	1490 ab	2.38 a	0.34 b
P banded with the seed			
(80+6)-20-0	1180 ab	2.48 a	0.30 b
(80+12)-40-0	1500 ab	2.48 a	0.31 b
(80+24)-80-0	1520 a	2.51 a	0.33 b

Means within columns with the same letter are not significantly different at the 0.05 significance level.

methods of placement. Table XVII lists the means of the various crop response parameters measured, by either rate of method of placement of phosphorus fertilizer. Results from the F-test indicate that grain phosphorus content was nearly significantly affected by method of phosphorus placement, broadcast and disced phosphorus producing a higher yield than phosphorus banded with the seed. These results indicate no advantage, in terms of grain yield or plant content of the three major nutrients, of phosphorus banded with the seed over broadcast and disced phosphorus.

The Bray-Mitscherlich equation can be expanded to the form $\log (A-y) = \log A = c_1 b - cx$, in which c is the efficiency factor for added units of phosphorus fertilizer, x. For this phosphorus placement methods experiment, c_1 values were calculated for individual plots from both experiments on the east farm, and an average c_1 for the farm obtained. Using this c_1, b's were obtained to replace the erroneous 0 kg/ha values for replications 1 and 4, and using the correct values for x, c values obtained for each method x rate combination in the phosphorus methods experiment. Results are reported in Table XVIII. In general, low rates of fertilizer phosphorus ranked higher in efficiency in producing yield response in a wheat crop during this growing season. No conclusions can be drawn regarding the efficiency of one method of placement versus the other. On this field no grain yield response to increments of added fertilizer was obtained because of limited rainfall (see Table XIX for rainfall data).

Method of Extraction of Phosphorus From Soils

Phosphorus content on each of 20 selected soils was determined by

TABLE XVII

MEANS OF CROP RESPONSE PARAMETERS BY RATE OR METHOD OF PLACEMENT OF FERTILIZER PHOSPHORUS, CORDELL, OKLAHOMA, 1979-1980

Method or Rate	Grain Yield	Grain			Forage		
		N	P	K	N	P	K
	kg/ha	%					
Banded with seed	1400	2.49	0.31	0.40	4.35	0.43	3.55
Broadcast and disced in	1460	2.48	0.34	0.40	4.26	0.43	3.36
PR > F	0.4728	0.8749	0.524	0.8270	0.4015	0.6536	0.0367*
22 kg/ha	1300	2.50	0.32	0.40	4.14	0.40	3.37
45 kg/ha	1470	2.50	0.33	0.41	4.50	0.44	3.56
90 kg/ha	1510	2.44	0.34	0.40	4.28	0.45	3.44
PR > F	0.4749	0.5861	0.5577	0.7393	0.0547	0.1149	0.2208

*Means significantly different at the 0.05 significance level.

TABLE XVIII

MEANS OF PHOSPHORUS EFFICIENCY FACTORS, C'S, EAST FARM PHOSPHORUS METHODS OF PLACEMENT EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Method Rate	Mean	Rank
Broadcast		
80-20-0	0.0356	2
80-40-0	0.0198	4
80-80-0	0.0084	5
Banded		
(80+6)-20-0	0.0393	1
(80+12)-40-0	0.0203	3
(80+24)-80-0	0.0074	6
LSD (0.05)	0.0257	

TABLE XIX

CORDELL, OKLAHOMA RAINFALL DATA,
JUNE 1979 - JUNE 1980

Year	Month	Precipitation		
		Monthly	Deviation From Long Term Average	Cumulative
		cm		
1979	June	11.56	+2.64	11.56
	July	9.09	+2.77	20.65
	August	7.44	+1.06	28.09
	September	0.43	-5.79	28.52
	October	4.80	-1.73	33.32
	November	2.16	-0.68	35.48
	December	1.83	-0.91	37.31
1980	January	4.42	+2.39	41.73
	February	2.11	-0.48	43.84
	March	5.59	-1.86	49.43
	April	4.52	-2.08	53.95
	May	25.63	+14.53	79.58
	June	4.22	-4.70	83.80

use of each of two chemical extractants, Bray P-1 and Mehlich, at each of three soil:extractant ratios. These data are recorded in Table XX. These soil phosphorus values were correlated to crop response parameters related to soil phosphorus content, Table XXI. Also, the soil phosphorus efficiency factors for each of these two sets of data (Tables XXII and XXIII) were correlated to grain yield and phosphorus content.

All correlations resulted in r^2 values no higher than 0.60 and thus no correlations were significant. These results can be attributed to the limitation encountered during the growing season of low moisture. This same type of study undertaken in a year having adequate rainfall would be beneficial in producing correlation data describing the extractant and soil:extractant ratio most suited for testing calcareous high-pH soils for phosphorus.

TABLE XX

BRAY P-1 AND MEHLICH PHOSPHORUS CONTENT DETERMINATIONS ON TWENTY SELECTED SOILS, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	State Lab Bray P-1	Bray P-1 Ratio 1:20	1:50	1:100
	kg/ha			
East Farm				
Phosphorus Terraces				
Terrace 1	54	54	69	75
Terrace 2	8	45	65	83
Terrace 3	12	51	78	97
Terrace 4	1	36	60	86
Phosphorus Methods Area				
Rep 1	0	4	3	70
Rep 2	17	28	41	62
Rep 3	28	33	49	65
Rep 4	0	35	56	77
West Farm				
Nitrogen Terraces				
Terrace 3				
Strip 1	3	3	54	97
Strip 2	4	27	61	125
Strip 3	8	3	88	114
Strip 4	12	45	91	114
Terrace 6				
Strip 1	38	40	95	96
Strip 2	40	40	108	137
Strip 3	11	7	104	141
Strip 4	11	11	96	130
Terrace 7				
Strip 1	3	31	85	102
Strip 2	6	51	95	112
Strip 3	9	39	96	118
Strip 4	4	59	88	109

TABLE XX (Continued)

Plot Identification	Mehlich P Ratio 1:20	1:50	1:100
	kg/ha		
East Farm			
Phosphorus Terraces			
Terrace 1	62	86	96
Terrace 2	72	86	92
Terrace 3	80	99	108
Terrace 4	67	72	85
Phosphorus Methods Area			
Rep 1	42	46	60
Rep 2	44	60	72
Rep 3	48	68	74
Rep 4	56	75	81
West Farm			
Nitrogen Terraces			
Terrace 3			
Strip 1	75	94	94
Strip 2	86	109	123
Strip 3	94	118	141
Strip 4	89	108	110
Terrace 6			
Strip 1	85	113	150
Strip 2	97	125	155
Strip 3	109	137	168
Strip 4	123	157	164
Terrace 7			
Strip 1	81	104	112
Strip 2	86	108	116
Strip 3	95	121	125
Strip 4	103	116	139

TABLE XXI

GRAIN YIELD AND PHOSPHORUS CONTENT OF WHEAT FROM TWENTY SELECTED PLOTS, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	Yield	Phosphorus Content
	kg/ha	—— % ——
East Farm		
Phosphorus Terraces		
Terrace 1	1190	0.38
Terrace 2	950	0.39
Terrace 3	850	0.92
Terrace 4	290	0.42
Phosphorus Methods Area		
Rep 1	350	0.35
Rep 2	990	0.45
Rep 3	1080	0.50
Rep 4	520	0.42
West Farm		
Nitrogen Terraces		
Terrace 3		
Strip 2	2270	0.38
Strip 3	2430	0.35
Strip 4	2720	0.41
Terrace 6		
Strip 2	220	0.33
Strip 3	310	0.33
Strip 4	940	0.36
Terrace 7		
Strip 2	2680	0.33
Strip 3	2480	0.33
Strip 4	2670	0.37

TABLE XXII

PHOSPHORUS EFFICIENCY FACTORS, C_1'S, CALCULATED FROM SOIL TEST PHOSPHORUS VALUES OBTAINED USING THE BRAY P-1 EXTRACTANT AT EACH OF THREE SOIL:EXTRACTANT RATIOS, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	State Lab Bray P-1	Bray P-1 Ratio 1:20	1:50	1:100
East Farm				
Phosphorus Terraces				
Terrace 1	0.0197	0.0197	0.0154	0.0141
Terrace 2	0.0450	0.0076	0.0054	0.0042
Terrace 3	0.0187	0.0046	0.0030	0.0024
Terrace 4	0.0681	0.0021	0.0013	0.0009
Phosphorus Methods Area				
Rep. 1	0.4867	0.1217	0.1622	0.0078
Rep. 2	0.0196	0.0117	0.0081	0.0053
Rep. 3	0.0187	0.0153	0.0103	0.0078
Rep. 4	--	--	--	--
West Farm				
Nitrogen Terraces				
Terrace 3				
Strip 2	0.1459	0.0650	0.0286	0.0139
Strip 3	0.0967	0.6878	0.0245	0.0189
Strip 4	0.0857	0.0992	0.0491	0.0392
Terrace 6				
Strip 2	0.0096	0.0064	0.0024	0.0019
Strip 3	0.0046	0.0582	0.0038	0.0028
Strip 4	0.0158	0.4000	0.0465	0.0345
Terrace 7				
Strip 2	0.1791	0.0877	0.0469	0.0400
Strip 3	0.0887	0.0644	0.0259	0.0213
Strip 4	0.2202	0.0871	0.0586	0.0474

TABLE XXIII

PHOSPHORUS EFFICIENCY FACTORS, C_1'S, CALCULATED FROM SOIL TEST PHOSPHORUS VALUES OBTAINED USING THE MEHLICH EXTRACTANT AT EACH OF THREE SOIL:EXTRACTANT RATIOS, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	Mehlich Ratio 1:20	1:50	1:100
East Farm			
Phosphorus Terraces			
Terrace 1	0.0171	0.0123	0.0110
Terrace 2	0.0049	0.0041	0.0038
Terrace 3	0.0029	0.0023	0.0021
Terrace 4	0.0011	0.0011	0.0009
Phosphorus Methods Area			
Rep. 1	0.0129	0.0119	0.0090
Rep. 2	0.0075	0.0054	0.0046
Rep. 3	0.0105	0.0074	0.0069
Rep. 4	--	--	--
West Farm			
Nitrogen Terraces			
Terrace 3			
Strip 2	0.0010	0.0161	0.0142
Strip 3	0.0228	0.0183	0.0153
Strip 4	0.0505	0.0417	0.0408
Terrace 6			
Strip 2	0.0026	0.0020	0.0016
Strip 3	0.0036	0.0029	0.0023
Strip 4	0.0365	0.0286	0.0274
Terrace 7			
Strip 2	0.0521	0.0417	0.0385
Strip 3	0.0261	0.0205	0.0198
Strip 4	0.0500	0.0442	0.0371

CHAPTER V

SUMMARY AND CONCLUSIONS

Due to lack of moisture during the 1979-1980 growing season at Cordell, Oklahoma, results on methods of extraction of phosphorus from high-pH soils are inconclusive. More work along these lines is needed on both pertinent topics-extractant used and soil:extractant ratio employed.

Evidence brought forth in this study indicates that the current soil test procedure and calibration in use in Oklahoma for nitrogen on wheat is accurately describing field nitrogen contents and fertilizer requirements. The same is true for the phosphorus calibration.

From this one year's data on one terraced field, sampling of a terraced area by terraces best divides the field along lines of transitions in soil nutrient contents and requires the least amount of work in acquiring a representative sample. If a terraced field is not sampled by terrace, it should at least be sampled separately from a surrounding level field receiving the same management practices. This recommendation separates sampling areas on the basis of soil properties as well as on the basis of management practices used over the area. Sampling of a terraced field should start at a distance above the footslope where soil properties reflect the properties of the terraced field and do not reflect the grade in properties to those of the surrounding level ground.

More analysis of the response of a crop to band placement of fertilizer phosphorus would contribute to knowledge of factors (soil types, rainfall, fertilizer rate, spacing of bands, etc.) which optimize plant use of this element.

The continued utilization of c_1 values to describe phosphorus behavior in the soil could be of benefit both in describing variations within a field of soil properties and in determining sufficiencies of various levels of soil phosphorus in producing a crop. The c value is also a useful parameter which could help describe the effectiveness of various phosphorus fertilizer materials and placement methods.

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APPENDICES

APPENDIX A

SOIL SAMPLE DATA

TABLE XXIV

INITIAL SOIL TEST PH, N, P, AND K VALUES, EAST FARM
TERRACED EXPERIMENT, CORDELL
OKLAHOMA, 1979-1980

Terrace Number	Initial Soil Test Value			
	pH	N	P	K
		kg/ha		
1	8.1	29	54	520
2	8.2	45	8	560
3	8.3	29	12	540
4	8.4	31	1	450

TABLE XXV

NITRATE- AND AMMONIUM-NITROGEN CONTENTS OF SELECTED SOILS, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	Soil Content NO_3-N	Soil Content NH_4-N
	kg/ha	kg/ha
East Farm Terraces		
Terrace 1	10	12
Terrace 2	13	14
Terrace 3	14	18
Terrace 4	10	18
East Farm P Methods Experiment		
Rep 1	16	26
Rep 2	12	13
Rep 3	9	13
Rep 4	8	12
West Farm N Rate Experiment		
Rep 1	73	30
Rep 2	82	27
Rep 3	81	26
Rep 4	46	22
West Farm Terraces		
Terrace 3		
Strip 1	59	12
Strip 2	61	12
Strip 3	55	13
Strip 4	49	12
Terrace 6		
Strip 1	43	8
Strip 2	36	7
Strip 3	51	12
Strip 4	81	10
Terrace 7		
Strip 1	31	15
Strip 2	62	11
Strip 3	58	12
Strip 4	73	11

TABLE XXVI

GRAIN YIELDS, INITIAL SOIL TEST P LEVELS, AND CALCULATED PHOSPHORUS PERCENT SUFFICIENCIES OF INDIVIDUAL PLOTS, WEST FARM TERRACED EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	Grain Yield	State Lab Soil Test P	Percent Sufficiency Calculated	Percent Sufficiency Fact Sheet 2225
	kg/ha	kg/ha		
West Farm Terraces				
Terrace 1				
	2797	132	91	100
	2739	152	89	100
	2514	156	82	100
Terrace 2				
	2846	78	93	100
	3013	85	98	100
	3071	95	100	100
Terrace 3				
	2269	4	74	25
	2426	8	79	25
	2719	12	87	45
Terrace 4				
	959	34	31	80
	1076	34	35	80
	1262	27	41	80
Terrace 5				
	1536	60	50	90
	949	40	31	80
	1340	45	44	80
Terrace 6				
	215	37	7	80
	313	11	10	25
	939	11	30	25
Terrace 7				
	2680	6	87	25
	2475	9	80	25
	2670	4	87	25
Terrace 8				
	1800	57	59	90
	2651	43	86	80
	2142	31	70	80

Three observations obtained for each yield or nutrient content, from each of three strips in each terrace.

APPENDIX B

FORAGE SAMPLE DATA

TABLE XXVII

FORAGE CONTENTS OF N, P, AND K, WEST FARM NITROGEN RATE EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Treatment N-P-K	Forage Content N	P	K
		%	
0-0-0			
	5.30	0.40	4.22
	5.50	0.47	4.38
	5.35	0.39	3.94
	4.84	0.39	3.97
25-0-0			
	5.30	0.42	4.46
	5.26	0.43	4.43
	5.24	0.37	4.09
	5.17	0.41	3.85
50-0-0			
	5.57	0.47	4.31
	5.27	0.46	4.10
	4.24	0.36	4.23
	5.05	0.39	3.99
100-0-0			
	5.50	0.49	4.27
	5.43	0.47	4.40
	5.16	0.37	3.75
	5.24	0.36	4.17

Four observations obtained for each nutrient content because of four-fold replication of treatments.

TABLE XXVIII

FORAGE CONTENTS OF N, P, AND K, EAST FARM TERRACED EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	Forage Content		
	N	P	K
	%		
East Farm Terraces			
Terrace 1	2.39	0.34	1.19
Terrace 2	2.80	0.38	1.21
Terrace 3	2.48	0.31	1.08
Terrace 4	1.48	0.28	1.22

TABLE XXIX

FORAGE CONTENTS OF N, P, AND K, EAST FARM P METHOD-OF-PLACEMENT EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Treatment	Forage Content N	Forage Content P	Forage Content K
	%	%	%
80-0-0	4.19	0.38	3.28
	4.26	0.36	3.36
	4.50	0.45	3.80
	4.18	0.44	3.71
Broadcast and Disced P			
80-0-0	3.74	0.37	3.13
	4.06	0.37	3.06
	4.16	0.41	3.28
	3.91	0.42	3.34
80-40-0	4.14	0.45	3.26
	4.47	0.42	3.58
	5.32	0.49	3.53
	4.24	0.42	3.80
80-80-0	4.45	0.53	3.36
	4.17	0.40	3.28
	4.39	0.44	3.58
	3.99	0.46	3.11
Banded P			
(80+6)-20-0	4.00	0.42	3.32
	4.39	0.37	3.24
	4.50	0.47	3.95
	4.38	0.40	3.65
(80+12)-40-0	4.42	0.48	3.37
	4.40	0.40	3.44
	4.53	0.44	3.63
	4.34	0.39	3.84
(80+24)-80-0	4.23	0.45	3.29
	4.42	0.43	3.61
	4.34	0.43	3.60
	4.22	0.44	3.67

Four observations obtained for each nutrient content because of four-fold replication of treatments.

APPENDIX C

GRAIN SAMPLE DATA

TABLE XXX

GRAIN YIELDS AND CONTENTS OF N, P, AND K, WEST FARM TERRACED EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	Grain			
	Yield	N	P	K
	kg/ha		%	
80-0-0				
Fertilized Strip				
Terrace 1	3100	2.28	0.32	0.50
Terrace 2	2920	2.31	0.35	0.48
Terrace 3	1930	2.52	0.47	0.57
Terrace 4	2180	2.62	0.35	0.53
Terrace 5	1030	2.24	0.32	0.48
Terrace 6	430	2.27	0.33	0.49
Terrace 7	2720	2.17	0.33	0.45
Terrace 8	1020	2.46	0.33	0.49
Check Strip				
Terrace 1	2800	2.16	0.37	0.53
Terrace 2	2850	2.02	0.32	0.46
Terrace 3	2270	2.26	0.38	0.50
Terrace 4	960	2.17	0.33	0.50
Terrace 5	1540	2.36	0.42	0.56
Terrace 6	220	2.00	0.33	0.47
Terrace 7	2680	1.90	0.33	0.48
Terrace 8	1800	2.15	0.39	0.54
40-0-0				
Fertilized Strip				
Terrace 1	2690	2.04	0.34	0.47
Terrace 2	3070	2.02	0.33	0.45
Terrace 3	2150	2.27	0.37	0.49
Terrace 4	660	2.44	0.36	0.48
Terrace 5	1070	2.19	0.38	0.46
Terrace 6	270	2.13	0.32	0.41
Terrace 7	1930	2.12	0.29	0.40
Terrace 8	1810	2.14	0.40	0.50
Check Strip				
Terrace 1	2740	2.11	0.34	0.39
Terrace 2	3010	2.05	0.31	0.36
Terrace 3	2430	2.30	0.35	0.49
Terrace 4	1080	2.09	0.35	0.51
Terrace 5	950	2.18	0.37	0.51
Terrace 6	310	1.98	0.33	0.44
Terrace 7	2480	2.04	0.33	0.44
Terrace 8	2650	1.95	0.47	0.50

TABLE XXX (Continued)

Plot Identification	Grain			
	Yield	N	P	K
	kg/ha	%		
80-0-0 Fertilized Strip				
Terrace 1	2790	2.08	0.42	0.37
Terrace 2	3150	2.15	0.45	0.29
Terrace 3	2650	2.49	0.46	0.52
Terrace 4	1490	2.36	0.39	0.47
Terrace 5	1200	2.20	0.35	0.47
Terrace 6	590	2.10	0.39	0.47
Terrace 7	720	2.16	0.31	0.44
Terrace 8	2520	2.31	0.49	0.52
Check Strip				
Terrace 1	2510	2.33	0.37	0.45
Terrace 2	3070	2.10	0.37	0.44
Terrace 3	2720	2.18	0.41	0.45
Terrace 4	1260	2.11	0.34	0.43
Terrace 5	1340	2.16	0.41	0.47
Terrace 6	940	1.88	0.36	0.43
Terrace 7	2670	1.99	0.37	0.44
Terrace 8	2140	2.00	0.43	0.48
40-0-0 Fertilized Strip				
Terrace 1	2840	2.14	0.32	0.43
Terrace 2	2790	2.04	0.39	0.43
Terrace 3	2650	2.21	0.38	0.43
Terrace 4	1150	2.10	0.35	0.43
Terrace 5	1250	2.25	0.36	0.44
Terrace 6	1040	2.00	0.31	0.40
Terrace 7	2430	2.28	0.36	0.47
Terrace 8	2050	2.34	0.35	0.46
Check Strip				
Terrace 1	2530	2.12	0.34	0.46
Terrace 2	3020	2.02	0.33	0.44
Terrace 3	2600	1.94	0.37	0.48
Terrace 4	730	2.13	0.40	0.48
Terrace 5	1510	2.15	0.40	0.49
Terrace 6	970	1.80	0.34	0.44
Terrace 7	2020	1.92	0.43	0.48
Terrace 8	3000	2.06	0.47	0.49

TABLE XXXI

GRAIN YIELDS AND CONTENTS OF N, P, AND K, WEST FARM NITROGEN RATE EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Treatment	Grain			
N-P-K	Yield	N	P	K
	kg/ha		%	
0-0-0	2900	2.57	0.33	0.48
	3200	2.54	0.38	0.54
	2780	2.59	0.35	0.51
	2760	2.18	0.36	0.47
25-0-0	2760	2.54	0.40	0.56
	3170	2.51	0.40	0.55
	3510	2.52	0.48	0.51
	3000	2.42	0.35	0.47
50-0-0	3280	2.47	0.46	0.52
	3160	2.62	0.41	0.54
	3090	2.60	0.43	0.56
	130	2.30	0.35	0.47
100-0-0	3390	2.49	0.45	0.59
	3150	2.66	0.44	0.58
	2830	2.82	0.38	0.54
	3380	2.58	0.44	0.65

Four observations obtained for each yield or nutrient content because of four-fold replication of treatments.

TABLE XXXII

GRAIN YIELDS AND CONTENTS OF N, P, AND K, EAST FARM TERRACED EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Plot Identification	Grain			
	Yield	N	P	K
	kg/ha		%	
Terrace 1				
	1420	1.74	0.41	0.40
Fertilized	1200	1.54	0.36	0.46
Strip	1310	1.56	0.38	0.43
	1450	1.56	0.34	0.46
	1220	1.64	0.45	0.55
Unfertilized	720	1.48	0.38	0.49
Strip	1270	1.72	0.36	0.48
	1560	1.96	0.33	0.42
Terrace 2				
	1640	2.18	0.30	0.39
Fertilized	1220	2.15	0.29	0.40
Strip	2220	2.08	0.34	0.42
	2300	1.98	0.34	0.41
	1120	1.87	0.44	0.51
Unfertilized	1020	1.64	0.35	0.44
Strip	610	1.54	0.35	0.41
	1070	1.79	0.40	0.47
Terrace 3				
	2200	2.00	0.36	0.42
Fertilized	2330	2.11	0.40	0.40
Strip	2210	2.04	0.33	0.41
	2280	2.08	0.33	0.41
	500	1.84	0.37	0.45
Unfertilized	380	1.76	0.42	0.45
Strip	860	1.68	0.47	0.46
	1660	1.88	0.41	0.47
Terrace 4				
	2100	2.34	0.40	0.41
Fertilized	1330	2.29	0.41	0.38
Strip	2000	2.11	0.40	0.39
	2170	2.06	0.36	0.38
	460	1.89	0.40	0.40
Unfertilized	260	1.80	0.44	0.42
Strip	240	1.87	0.47	0.50
	150	1.76	0.37	0.44

Four observations obtained for each yield or nutrient content because of four-fold replication of treatments.

TABLE XXXIII

GRAIN YIELDS AND CONTENTS OF N, P, AND K, EAST FARM P METHOD-OF-PLACEMENT EXPERIMENT, CORDELL, OKLAHOMA, 1979-1980

Treatment	Grain			
	Yield	N	P	K
	kg/ha		%	
0-0-0	350	2.29	0.35	0.37
	990	2.01	0.45	0.42
	1080	1.99	0.50	0.45
	520	1.83	0.42	0.43
80-0-0	840	2.47	0.30	0.41
	820	2.62	0.28	0.40
	1190	2.75	0.31	0.41
	1360	2.60	0.34	0.43
Broadcast and Disced P				
80-20-0	1060	2.52	0.33	0.42
	1330	2.60	0.34	0.42
	1680	2.53	0.37	0.41
	1640	2.46	0.33	0.35
80-40-0	1240	2.46	0.34	0.41
	1670	2.52	0.37	0.39
	1840	2.52	0.34	0.38
	1060	2.60	0.34	0.46
80-80-0	1730	2.52	0.37	0.40
	1380	2.28	0.35	0.42
	1220	2.10	0.33	0.40
	1650	2.62	0.32	0.39
Banded P				
(80+6)-20-0	1100	2.36	0.28	0.37
	1160	2.53	0.31	0.40
	1190	2.56	0.34	0.41
	1270	2.47	0.27	0.39
(80+12)-40-0	1640	2.48	0.28	0.42
	1280	2.66	0.34	0.42
	1630	2.40	0.31	0.39
	1430	2.36	0.32	0.39
(80+24)-80-0	1350	2.34	0.29	0.41
	1700	2.60	0.32	0.40
	1190	2.52	0.33	0.43
	1860	2.58	0.37	0.39

Four observations obtained for each yield or nutrient content because of four-fold replication of treatments.

VITA

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