A STUDY OF THE DISTRIBUTION OF TOTAL PHOSPHORUS IN THE MECHANICAL SEPARATES OF TWO SIMILAR REDDISH PRAIRIE SOIL PROFILES

By

DARYL DAVIS

Bachelor of Science

Oklahoma State University

1955

Master of Science

1959

Submitted to the faculty of the Graduate School
of the Oklahoma State University in partial
fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
January, 1959

A STUDY OF THE DISTRIBUTION OF TOTAL PHOSPHORUS IN
THE MECHANICAL SEPARATES OF TWO SIMILAR
REDDISH PRAIRIE SOIL PROFILES

Thesis Approved:

Lester W. Reed
Thesis Adviser

Fenton Gray

Billy B. Tucker

Robert MacVicar
Dean of the Graduate School

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Agronomy Department of Oklahoma State University for the financial assistance and laboratory facilities which made this study possible. The author is also grateful to the Agronomy Department Staff for their helpful advice and critcisms.

Special recognition is due Dr. L. W. Reed, major thesis adviser, for his guidance and helpful criticisms throughout the research study and in preparation of this thesis. The writer also wishes to thank Miss Nancy Stewart for typing the manuscript and Mr. James Mulkey for proofreading the final copy.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

From the standpoint of abundance and availability of nutrient elements, the phosphorus status of the soil is the first limiting factor in maintaining a permanent and successful agriculture program. The phosphorus level of a soil may very easily become critical since the amount of naturally occurring phosphorus in most soils is usually low.

To emphasize the importance of phosphorus in agriculture, Millar (9)[1] states that the world use of phosphoric acid in fertilizer has increased approximately 47% for the period from 1946-47 to 1950-51. Millar also reported that over 80% of the phosphorus applied to American soils in fertilizer is in the available form at the time of application. However, only 5-15% of this phosphorus is removed by the first crop.

Although there is an extensive literature on the forms of phosphorus in soils, information pertaining to the phosphorus content of the various mechanical separates is limited. Since the release of phosphorus to both plants and extracting reagents probably depends on soil particle size as well as chemical forms of phosphorus, more work should be conducted pertaining to the total amount and solubility of phosphorus in the several soil separates.

The purpose of this study was to determine the total phosphorus content of the several soil separates. It was hoped that this information would help to elucidate the differences in phosphatic fertilizer response between some similar Reddish Prairie soils.

---

[1]Figures in parenthesis refer to Literature Cited.

REVIEW OF LITERATURE

Early work pertaining to the chemical composition of soil colloids gave some indication that soil phosphorus is concentrated in the finer size soil fractions. In 1924, Robinson and Holmes (11) found that there was more phosphorus in the colloidal soil fraction than was present in the whole soil. Byers, et al (5) found much the same trend in their investigation of soil colloids.

Caldwell and Rost (6) made a study of the chemical composition of clay fractions separated from representative Black Prairie soils of Minnesota, from a Chernozem, and from a Gray-Brown Podzolic profile. They found the chemical composition of the clay was fairly uniform except for phosphorus content. The A horizon of the three soils was richest in phosphorus in every case and usually declined steadily with profile depth. However, the phosphorus content of three of the Black Prairie soil profiles increased in the C horizon. They also found that the phosphorus content of the clay varied considerably between the Great Soil Groups and in a descending order of Gray-brown Podzolic, Black Prairie, and Chernozem.

Williams and Saunders (15) measured the readily soluble phosphorus in some soils of Scotland by three different extraction methods. They found that most of the subsoil phosphorus was derived from acid soluble phosphorus in the coarser separates, particularly the fine sands. There was also strong evidence that the silt and fine sand separates made a major contribution to topsoil phosphorus values. The amount of phosphorus was directly related to parent material, with the highest phosphorus percentages in soils derived from basic igneous rocks. They concluded that the dominant process in acid soluble phosphorus extraction was apparently the dissolution of calcium-bound phosphates from the coarse soil particles. They also suggested that the usefullness of correlation between crop response and readily soluble phosphorus as a criteria of the phosphorus status in soils of Northeastern Scotland depended on the nature of the parent material.

Aldrich and Buchanan (1) made a study of the phosphorus content of soils from southern California and of the parent rocks from which these soils were derived. They found that the dominant factor affecting the phosphorus content of these soils was the amount of phosphorus in the parent rock material from which the soils were derived. With citrus trees as the indicator crop, it was determined that phosphorus deficiencies were more generally related to a low supply of total phosphorus than to any one level of the available phosphorus fractions.

Williams and Saunders (14) studied the phosphorus distribution in seven soil profiles representing four main soil associations of north-eastern Scotland. There were three pairs of soils with corresponding freely drained and poorly drained members. Total phosphorus was high throughout the profiles, but in each soil it was highest in the topsoil with the exception of the granitic soil pair. Low total phosphorus values were obtained for the first subsoils of the granitic pair, but in all other profiles the tendency was for total phosphorus to decrease down the profile to a certain depth and then increase in the lower horizons. Any decrease in total phosphorus with profile depth was attributed to a lower organic phosphorus content in the subsoil and any increase was due to the increase in inorganic phosphorus. With respect to particle size the variation in phosphorus distribution was great and was inconsistent for different soils. Total phosphorus was normally highest in the clay and lowest in the coarse sand. An exception to this observation was reported for the gleyed subsoils where the fine sands were higher in total phosphorus than the clays. Total inorganic phosphorus, in all topsoils, was normally highest in the clay fraction. However, the phosphorus in the sands was mostly inorganic and in approximately one half of the samples studied, including the soils derived from basic igneous rocks and gleyed subsoils, the fine sands were higher in inorganic phosphorus than the clays. In the topsoils, the coarse sands accounted for 12-22 percent of the total inorganic phosphorus, 18-50 percent for the fine sands, and 34-62 percent for the combined sands. The tendency was for these proportions to increase with profile depth, and in gleyed subsoils the phosphorus content for the combined sands was 70-80 percent of the total inorganic phosphorus. The main effect of the parent material was that the sands, particularly the fine sands, accounted for higher proportions of total phosphorus in the soils derived from basic igneous rocks as compared to those soils derived from acidic igneous rocks. Soils from basic igneous rocks were also higher in iron and aluminum.

Allaway and Rhoades (2) found that phosphorus accumulates in soils as surface adsorbed phosphates, or as combinations of iron and aluminum phosphates, or both. Their work was conducted on the more highly leached and acid soils derived from loess parent material of Nebraska. In a study of some genetically related loess parent material soils of Iowa, Godfrey and Riecken (7) concluded that loss of soil phosphorus by leaching had occurred since the phosphorus content in the A horizon was not high enough to account for the phosphorus lost from the B horizon of any of the five profiles studied. They reported that vertical distribution of phosphorus was altered by organic matter accumulations in the surface horizons and possibly by downward movement of phosphorus in suspension or in true solution. All the profiles studied appeared to be changing in total phosphorus content, but at rates coincidental with the degree of profile developement. The tendency was for total phosphorus in the A horizon to decrease in relation to that of the C horizon as profile development progressed. They also reported that the decrease in total phosphorus in the A horizon was paralleled with the decrease in total nitrogen content. They believed that the decrease in organic matter content of the Planosol, as compared to soils of the Wiesenboden soil developement stage, was caused by gradual movement of phosphorus from the A to the B horizon of the Planosol or complete removal of phosphorus from the solum. In this way the phosphorus became positionally as well as chemically less available to plants, and would cause a subsequent decrease in plant growth due to phosphorus deficiency as profile developement progressed. Therefore, the cycle of phosphorus weathering may be an important contributing factor to the lower organic matter content of Planosols as compared to Wiesenboden soils.

Bray and Dickman (3) contend that the adsorption mechanism of a soil acts to keep the phosphate concentration in water solution at a low level at any given time. As more phosphorus is removed either by plant absorption or by leaching, the phosphorus equilibrium is shifted from the adsorption complex to the solution phase. However, this may be an over-simplified explanation.

In comparing the phosphate fixing ability of kaolinite, halloysite, and bentonite, it was observed that kaolinite and halloysite could fix considerable amounts of phosphorus when the minerals are finely ground (12). X-ray patterns of phosphated kaolinite show an amorphous structure, but are distinctly crystalline for phosphated halloysite. When the two minerals were dephosphated the X-ray patterns of kaolinite showed a restoration of crystalline structure, but the structure of dephosphated halloysite was amorphous. The changes in X-ray patterns were probably caused by replacement of hydroxyl ions at the cleavage planes by phosphate tetrahedra, and X-ray pattern restoration was attributed to replacement of phosphate tetrahedra by hydroxyl ions. Therefore, phosphate fixation by this mechanism would be a simple ionic exchange between ions in solution and the component hydroxyl ions of the clay mineral lattice.

METHODS AND MATERIALS

This study of two similar Reddish Prairie soils was conducted to determine the phosphorus content of the several soil separates. It was postulated that the data obtained should provide some explanation of why the two soils studied may respond differently to phosphorus fertilizer treatment.

Description of the soils studied.

The soils were representative of the Reddish Prairie soils of central Oklahoma. Zaneis No. 1 and Zaneis No. 2 profiles were sampled in central Payne county. Samples of Kingfisher No. 1 and No. 2 were taken from central Kingfisher county and south-central Kingfisher county on the Kingfisher-Oklahoma county line respectively. The A horizons of the Zaneis profiles are dark brown slightly acid loams with dark reddish-brown moderately acid clay loam or silty clay loam B horizons. The A horizons of the Kingfisher profiles are brown or reddish-brown slightly acid silt loams with reddish-brown very slightly acid silty clay loam B horizons. All of the samples were taken from virgin profiles in native grassland meadows. The profiles are described in detail in the Appendix.

Laboratory analysis of the soil samples.

The soils were air dried, crushed with a steel roller to pass a 20-mesh sieve, and stored in one gallon ice cream cartons.

Available phosphorus was determined according to the method of Bray and Kurtz (4). Total phosphorus removed by perchloric acid digestion was determined by a method outlined by Harper (8).

For determination of phosphorus in the residue remaining after perchloric acid digestion, the residue and filter paper were placed in a crucible and ashed at 400° C for 10-12 hours in a muffle furnace. After cooling, the residue was transferred to a 100 ml. "Teflon" beaker, and moistened with 2-3 ml. of distilled water. The water was evaporated on a hot plate at very low heat. After evaporation was complete the residue was digested with 48% hydrofluoric acid and filtered on #42 Whatman paper and the extract was set aside for phosphorus analysis. The colorimetric method of Harper (8) was used to determine the amount of phosphorus in the hydrofluoric acid extract.

Mechanical separates for phosphorus analysis were obtained by the beaker method for mechanical analysis as outlined by Piper (10). Soil samples of 100 grams each were treated with hydrogen peroxide to remove organic matter. After organic matter oxidation the samples were brought to 500 ml. volume with distilled water and treated with 100 ml. of 2N HCl to flocculate the clay. After thorough mechanical dispersion the samples were allowed to stand for one hour. The samples were then brought to one liter volume, mechanically dispersed, and left undisturbed for another hour. The samples were then washed with 2-2½ liters of distilled water by alternately siphoning the supernatant liquid and adding distilled water to the one liter mark of the beakers. After washing, the samples were transferred to a 150 mesh per linear inch sieve and washed thoroughly to remove the very fine sand, silt, and clay. The coarse-fine sand retained on the sieve was transferred to a beaker and placed in the oven to dry. As each of the mechanical separates were obtained they were placed in the oven, dried at 90-100° C for 48-72 hours, weighed, and stored in small coin envelopes.

The clay was dispersed with 1N NaOH and sufficient distilled water was added to bring the suspension to the one liter mark on the beakers. The residue was stirred thoroughly and allowed to stand for the time neccessary for silt and very fine sand particles to settle below the 5 cm. mark. The turbid suspension was siphoned to the 5 cm. mark and stored in four gallon glazed earthenware crocks. The remaining clay was dispersed with ammonium hydroxide and the containers refilled to the one liter mark with distilled water. The process of dispersing the clay and siphoning the turbid suspension was continued until only negligible amounts of clay remained in suspension. The clay in the crocks was flocculated with acetic acid and further concentrated by siphoning and discarding the supernatant liquid.

The very fine sand and silt was separated by mechanically dispersing the very fine sand-silt residue in a one liter graduated cylinder and siphoning the turbid silt suspension to a depth of 10 cm. The necessary time lapse for very fine sand particles to settle 10 cm. was obtained from the nomographs by Jackson (13). The silt suspensions were stored in clean two liter bottles and allowed to stand for 2-3 days. The silt was concentrated by siphoning and discarding the supernatant liquid. The silt suspensions were then washed into beakers and dried, weighed and stored. The percentages of coarse-fine sand, very fine sand, silt, and clay were obtained by correcting for loss of organic matter from the original 100 gram soil sample.

Total phosphorus in each of the separates was determined by perchloric acid digestion and developement of the molybdate color complex according to a procedure by Harper (8). Total phosphorus removed from the perchloric acid residue by hydrofluoric acid digestion was determined colorimetrically according to the procedure outlined above.

RESULTS

Zaneis No. 1.

Available phosphorus is low in the surface horizon as indicated by the dilute fluoride-dilute acid soluble phosphorus extraction method of Bray and Kurtz (Table 1), and diminishes with profile depth to very low or immeasurable amounts in the lower horizons. The distribution of available phosphorus with profile depth follows the same distribution pattern as total "reserve" phosphorus (Figure 1). NOTE. Hereafter the term total "reserve" phosphorus will be used for reporting phosphorus removed by perchloric acid digestion plus that phosphorus removed from the perchloric acid residue by hydrofluoric acid digestion.

TABLE I-ZANEIS NO. 1

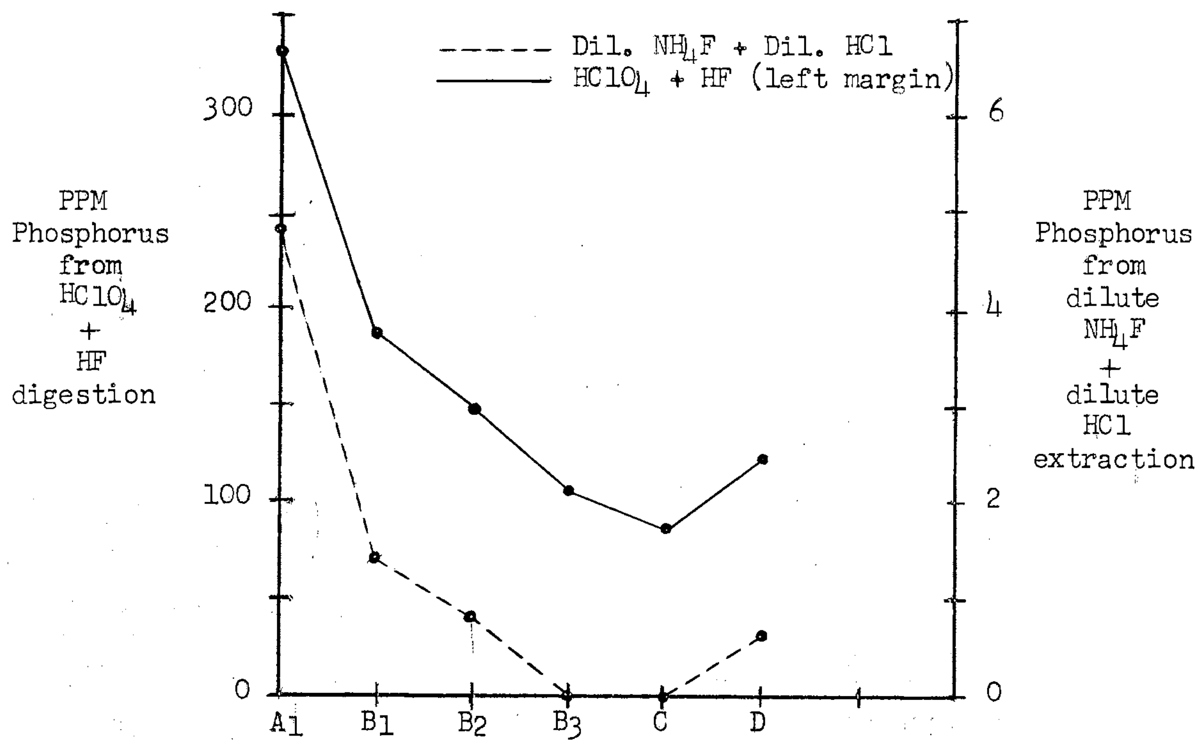
DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS*

Horizon	PPM Phosphorus
A1	4.8
B1	1.4
B2	0.8
B3	---
C	---
D	0.6

* Extracted with 0.03N NH_4F + 0.025N HCl, 1:7 soil-solution ratio for one minute.

Figure 1 - Zaneis No. 1

COMPARISON OF THE DISTRIBUTION OF TOTAL PHOSPHORUS AND DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS



Total phosphorus removed from the whole soil by perchloric acid digestion is low in the surface horizon and decreases steadily with profile depth (Table II, Part II). The amount of phosphorus removed from the perchloric acid "soil-residue" by concentrated hydrofluoric acid digestion also decreases with profile depth with the exception of the lowest horizon (Table II, Part II).

The sharp increase in total phosphorus removed from the lowest horizon by hydrofluoric acid digestion corresponds to an increase in coarse-fine sand separates and suggests that the ease with which total "reserve" phosphorus is removed from the Zaneis No. 1 profile may be very closely associated with particle size (Table III).

TABLE II - ZANEIS No. 1

PPM OF TOTAL "RESERVE" PHOSPHORUS OBTAINED FROM:

	PART I			PART II		
	Mechanical separates			Whole soil		
Horizon	$HClO_4$ Digest.	HF Digest.	Total*	$HClO_4$ Digest.	HF Digest.	Total*
A_1	81.7	5.4	87.1	210.4	122.0	332.4
B_1	82.5	9.5	92.0	164.0	24.0	188.0
B_2	106.6	4.9	111.5	122.4	26.4	148.8
B_3	84.3	7.5	91.8	73.6	31.0	104.6
C	92.1	5.8	97.9	57.6	29.0	86.6
D	71.7	3.4	75.1	25.6	98.0	123.6

* PPM of total phosphorus from perchloric acid digestion plus the PPM of total phosphorus from hydrofluoric acid digestion is reported as total "reserve" phosphorus.

TABLE III

MECHANICAL ANALYSIS - ZANEIS No. 1

	Percentage of each size separate*				
Horizon	Coarse-fine sand	Very fine sand	Silt (all)	Clay (all)	Total
A_1	16.37	22.99	40.22	17.09	96.97
B_1	14.93	21.28	36.27	25.24	97.72
B_2	12.12	14.73	34.86	34.20	95.91
B_3	18.76	22.39	27.22	28.38	96.75
C	29.62	21.76	23.02	23.08	97.48
D	74.11	13.16	3.82	8.80	99.89

* The percentages are corrected to account for weight loss due to organic matter oxidation.

The clay separate is much richer in total phosphorus according to both the perchloric acid and hydrofluoric acid digestion methods (Tables IV and V respectively). The differences in total phosphorus content of the sand and silt separates are inconsistent between horizons by the perchloric acid digestion method. However, there is a great difference in the amount of phosphorus removed from the coarse-fine sand, very fine sand, and silt separates by concentrated hydrofluoric acid digestion. Generally, minimum phosphorus removal by hydrofluoric acid is coincidental with an increase in degree of weathering (decrease in particle size). The much higher phosphorus content of the silt separate from the lower horizon is probably caused by clay contamination due to incomplete mechanical separation when the mechanical analysis was made.

From a comparison of the relationship of phosphorus removed by perchloric acid digestion and the phosphorus removed by concentrated hydrofluoric acid digestion it is evident that total "reserve" phosphorus held by the sands, particularly the coarse-fine sands, is more difficult to remove than the phosphorus held by the clay in this soil (Table VI).

TABLE IV - ZANEIS No. 1

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay
A_1	61.2	30.0	40.4	284.0
B_1	55.2	44.8	44.8	192.0
B2	48.8	42.0	51.2	224.0
B_3	29.2	34.4	44.4	208.0
C	24.8	37.6	48.0	284.0
D	31.2	37.6	77.3	190.0

TABLE V - ZANEIS No. 1

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay
A_1	12.8	----	----	19.2
B_1	11.4	2.8	----	28.6
B_2	3.2	4.0	----	11.4
B_3	3.2	4.0	----	21.0
C	2.8	2.8	----	19.0
D	4.4	----	2.3	**

* Residue left from the perchloric acid digestion is redigested with 48% hydrofluoric acid.

** Sample lost.

TABLE VI - ZANEIS No. 1

RELATIONSHIP OF PHOSPHORUS REMOVED BY PERCHLORIC ACID AND HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Combined sands	Silt	Clay
A_1	4.8	----	7.1	----	14.8
B_1	4.8	16.0	7.0	----	6.7
B_2	15.1	10.5	12.6	----	19.7
B_3	9.1	8.6	8.8	----	9.9
C	8.9	13.4	11.1	----	14.9
D	7.1	----	15.6	33.6	**

* The numbers represent the ratio of PPM of phosphorus removed by perchloric acid digestion to the PPM of phosphorus removed by hydrofluoric acid digestion. A narrow ratio indicates minimum phosphorus removal by perchloric acid digestion.

** Sample to be used for hydrofluoric acid digestion was lost.

According to data reported in Table VII the perchloric acid digestion method is approximately 21-87% efficient in the removal of total "reserve" phosphorus from the whole soil of the Zaneis No. 1 profile. Data in Tables VIII and IX shows the amounts of phosphorus the mechanical separates contribute to the whole soil by perchloric acid and hydrofluoric acid digestion.

TABLE VII - ZANEIS No. 1

COMPARATIVE EFFICIENCY OF THE REMOVAL OF TOTAL PHOSPHORUS BY TWO METHODS OF DIGESTION

	Percent of total phosphorus removed from the whole soil by:	
Horizon	Perchloric acid	Hydrofluoric acid*
A_1	63.3	36.7
B_1	87.2	12.8
B_2	82.3	17.7
B_3	70.4	29.6
C	66.5	33.5
D	20.7	79.3

* Digestion of the residue left from the perchloric acid digestion with 48% hydrofluoric acid.

TABLE VIII - ZANEIS No. 1

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay	Total	Whole soil*
A_1	10.0	6.9	16.3	48.5	81.7	210.4
B_1	8.2	9.5	16.3	48.5	82.5	164.0
B_2	5.9	6.2	17.9	76.6	106.6	122.4
B_3	5.5	7.7	12.1	59.0	84.3	73.6
C	7.4	8.2	11.1	65.6	92.1	57.6
D	23.1	5.0	29.5	14.1	71.7	25.6

* The figures in this column represent total phosphorus in the soil before removal of the organic matter and before mechanical separations were made.

TABLE IX - ZANEIS No. 1

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay	Total	Soil residue**
A_1	2.1	----	----	3.3	5.4	122.0
B_1	1.7	0.6	----	7.2	9.5	24.0
B_2	0.4	0.6	----	3.9	4.9	26.4
B_3	0.6	0.9	----	6.0	7.5	31.0
C	0.8	0.6	----	4.4	5.8	29.0
D	3.3	----	0.1	***	3.4	98.0

* Data were obtained by multiplying PPM of phosphorus from hydrofluoric acid digestion times the percent of each separate for the corresponding horizon.

** The residue left from perchloric acid digestion of the whole soil is redigested with 48% hydrofluoric acid.

*** Sample lost.

Zaneis No. 2.-

The amount of available phosphorus is very low in the A and upper B horizon and in the remainder of the profile it is too low for quantitative measurement by the method of analysis used (Table X). The general trend in available phosphorus distribution with profile depth is fairly consistent with total "reserve" phosphorus distribution (Figure 2).

TABLE X - ZANEIS No. 2

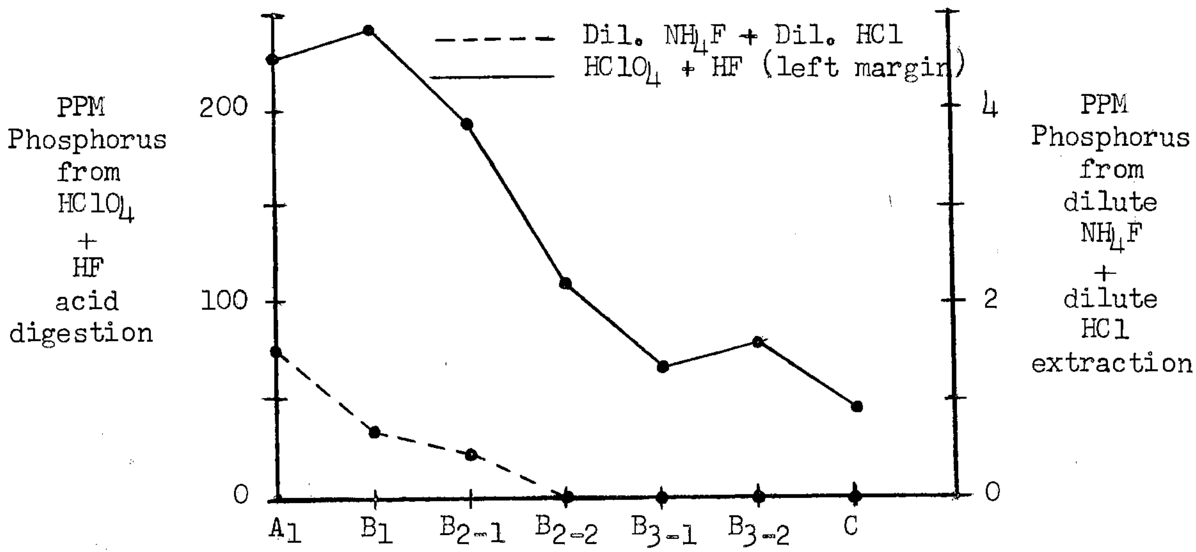
DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS*

Horizon	PPM Phosphorus
A_1	1.5
B_1	0.7
B_{2-1}	0.5
B_{2-2}	---
B_{3-1}	---
B_{3-2}	---
C	---

* Extracted with 0.03N NH_4F + 0.025N HCl, 1:7 soil solution ratio for one minute.

Figure 2 - Zaneis No. 2

COMPARISON OF THE DISTRIBUTION OF TOTAL PHOSPHORUS
AND DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS



Data in Table XI shows the percent of each size separate for the horizons of the Zaneis No. 2 profile.

Total phosphorus removed from the whole soil by perchloric acid digestion decreases steadily with profile depth from 168.0 PPM in the surface horizon to 41.6 PPM in the lowest horizon (Table XII, Part II). Total phosphorus content of the mechanical separates is much higher for the clay than for any of the other separates according to both the perchloric acid and hydrofluoric acid digestion methods (Tables XIII and XIV). The influence of weathering (decrease in particle size) on the ease with which phosphorus is removed by perchloric acid digestion is shown by the data reported in Table XIV and by the ratios reported in Table XV.

TABLES XI

MECHANICAL ANALYSIS - ZANEIS No. 2

	Percentage of each size separate*				
Horizon	Coarse-fine sand	Very fine sand	Silt (all)	Clay (all)	Total
A_1	30.17	23.59	26.55	16.68	96.99
B_1	19.24	23.58	23.88	28.78	95.48
B_{2-1}	19.51	21.46	24.64	31.45	97.06
B_{2-2}	18.73	25.30	26.09	27.29	97.41
B_{3-1}	20.37	24.13	27.41	25.72	97.63
B_{3-2}	23.17	22.18	28.40	23.99	97.74
C	30.57	22.00	24.67	20.73	97.97

* The percentages are corrected to account for weight loss due to organic matter oxidation.

TABLE XII - ZANEIS No. 2

PPM OF TOTAL "RESERVE" PHOSPHORUS OBTAINED FROM:

	PART I			PART II		
	Mechanical separates			Whole soil		
Horizon	$HClO_4$ Digest.	HF Digest.	Total*	$HClO_4$ Digest.	HF Digest.	Total*
A_1	63.6	5.1	68.7	168.0	58.6	226.6
B_1	98.2	19.9	118.1	156.0	86.0	242.0
B_{2-1}	124.2	7.9	132.1	137.6	55.2	192.8
B_{2-2}	80.5	7.0	87.5	88.0	22.0	110.0
B_{3-1}	82.1	5.4	87.5	61.6	4.4	66.0
B_{3-2}	83.7	4.1	87.8	45.6	34.4	80.0
C	67.0	2.8	69.8	41.6	4.0	45.6

* PPM of total phosphorus from perchloric acid digestion plus the PPM of total phosphorus from hydrofluoric acid digestion is reported as total "reserve" phosphorus.

TABLE XIII - ZANEIS No. 2

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay
A_1	35.2	38.8	39.6	200.0
B_1	28.0	38.4	42.0	256.0
B_{2-1}	28.4	46.4	48.0	308.0
B_{2-2}	26.4	41.2	48.8	192.0
B_{3-1}	33.6	40.4	51.2	200.0
B_{3-2}	24.8	38.4	52.0	228.0
C	29.2	42.8	52.8	172.0

TABLE XIV - ZANEIS No. 2

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay
A_1	4.8	----	----	22.2
B_1	4.4	----	----	66.4
B_{2-1}	6.8	----	----	21.0
B_{2-2}	5.0	6.4	----	16.6
B_{3-1}	3.6	2.8	----	15.5
B_{3-2}	3.6	----	5.0	7.8
C	4.8	----	----	6.2

* Residue left from the perchloric acid digestion is redigested with 48% hydrofluoric acid.

TABLE XV - ZANEIS No. 2

RELATIONSHIP OF PHOSPHORUS REMOVED BY PERCHLORIC ACID AND HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Combined sands	Silt	Clay
A1	7.3	----	15.4	----	9.0
B1	6.4	----	15.1	----	3.9
B2-1	4.2	----	11.0	----	14.7
B2-2	5.3	6.4	5.9	----	11.6
B3-1	9.3	14.4	11.6	----	12.9
B3-2	6.9	----	17.6	10.4	29.2
C	6.1	----	15.0	----	27.7

* The numbers represent the ratio of PPM of phosphorus removed by perchloric acid digestion to the PPM of phosphorus removed by hydrofluoric acid digestion. A narrow ratio indicates minimum phosphorus removal by perchloric acid digestion.

Although more total phosphorus is removed from the clay by hydrofluoric acid digestion than is removed from the other soil separates, the ratio of phosphorus obtained by hydrofluoric acid digestion to the phosphorus removed by perchloric acid digestion shows that phosphorus in the clay of this soil is more easily removed by perchloric acid digestion than the phosphorus in the combined sand separates.

The data presented in Table XVI shows that the perchloric acid digestion method removes 57.0-93.0% of the total "reserve" phosphorus from the whole soil of the Zaneis No. 2 profile.

The amounts of total phosphorus the soil separates contribute to the whole soil when digested with perchloric acid and hydrofluoric acid are shown in Tables XVII and XVIII.

TABLE XVI - ZANEIS No. 2

COMPARATIVE EFFICIENCY OF THE REMOVAL OF TOTAL PHOSPHORUS BY TWO METHODS OF DIGESTION

	Percent of total phosphorus removed from the whole soil by:	
Horizon	Perchloric acid	Hydrofluoric acid*
A_1	74.1	25.9
B_1	64.5	35.5
B_{2-1}	71.3	28.7
B_{2-2}	80.0	20.0
B_{3-1}	93.0	7.0
B_{3-2}	57.0	43.0
C	91.2	8.8

* Digestion of the residue left from perchloric acid digestion with 48% hydrofluoric acid.

TABLE XVII - ZANEIS No. 2

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay	Total	Whole soil*
A_1	10.6	9.2	10.5	33.4	63.6	168.0
B_1	5.4	9.1	10.0	73.7	98.2	156.0
B_{2-1}	5.5	10.0	11.8	96.9	124.2	137.6
B_{2-2}	4.9	10.4	12.7	52.4	80.5	88.0
B_{3-1}	6.8	9.8	14.0	51.4	82.1	61.6
B_{3-2}	5.8	8.5	14.8	54.7	83.7	45.6
C	8.9	9.4	13.0	35.7	67.0	41.6

* The figures in this column represent total phosphorus in the soil before removal of the organic matter and before mechanical separations were made.

TABLE XVIII - ZANEIS No. 2

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay	Total	Soil residue**
A_1	1.4	----	----	3.7	5.1	58.6
B_1	0.8	----	----	19.1	19.9	86.0
B_{2-1}	1.3	----	----	6.6	7.9	55.2
B_{2-2}	0.9	1.6	----	4.5	7.0	22.0
B_{3-1}	0.7	0.7	----	4.0	5.4	4.4
B_{3-2}	0.8	----	1.4	1.9	4.1	34.4
C	1.5	----	----	1.3	2.8	4.0

* Data were obtained by multiplying PPM of phosphorus from hydrofluoric acid digestion times the percent of each separate for the corresponding horizon.

** The residue left from perchloric acid digestion of the whole soil is redigested with 48% hydrofluoric acid.

Kingfisher No. 1.

Data reported in Table XIX shows that available phosphorus is low in the surface horizon. However, available phosphorus is uniformly distributed with profile depth. The general distribution of available phosphorus with profile depth is fairly consistent with the total "reserve" phosphorus distribution (Figure 3).

TABLE XIX - KINGFISHER No. 1

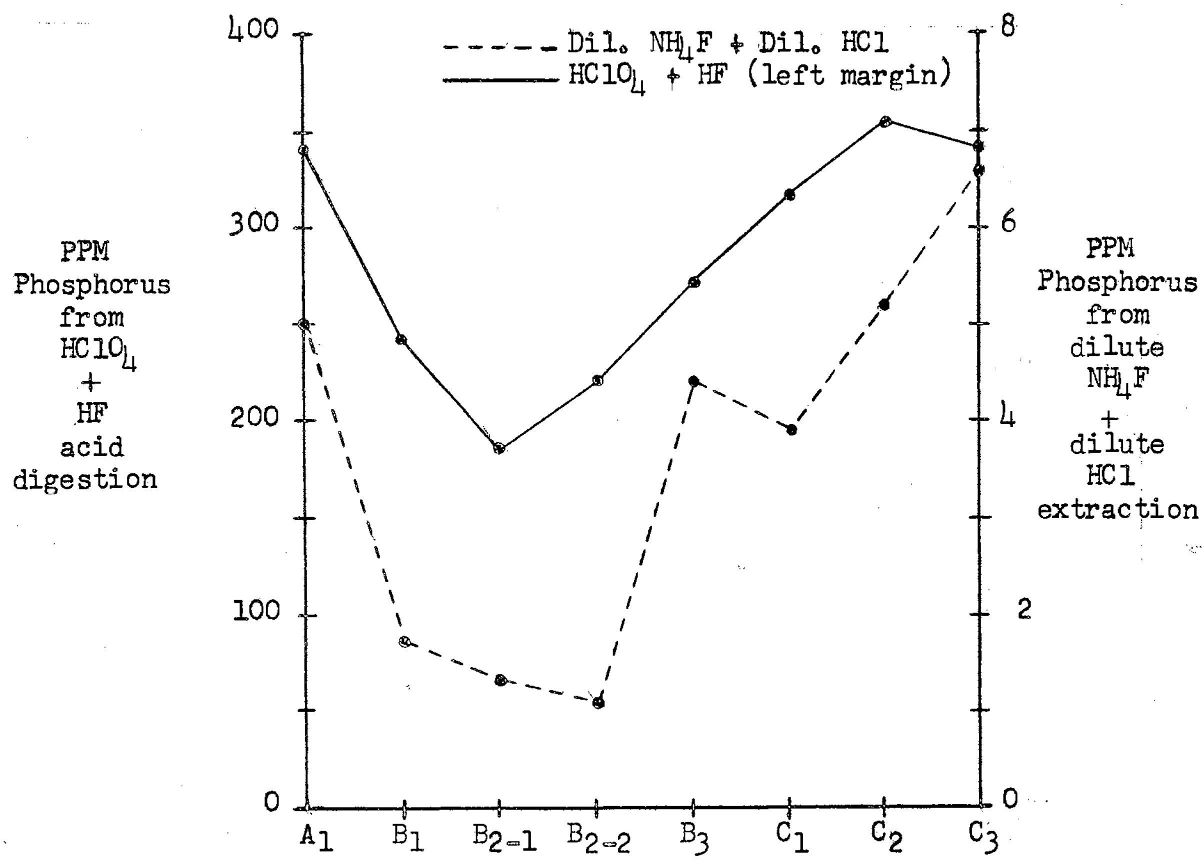
DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS*

Horizon	PPM Phosphorus
A1	5.0
B_1	1.7
B_{2-1}	1.3
B_{2-2}	1.1
B_3	4.4
C_1	3.9
C_2	5.2
C_3	6.6

* Extracted with 0.03N NH_4F + 0.025N HCl, 1:7 soil solution ratio for one minute.

Figure 3 - Kingfisher No. 1

COMPARISON OF THE DISTRIBUTION OF TOTAL PHOSPHORUS AND DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS



The percent of each size separate for the horizons of Kingfisher No. 2 is shown in Table XX.

Total phosphorus removed from the whole soil by perchloric acid digestion is not high, but is uniformly distributed throughout the entire profile (Table XXI, Part II). The very low phosphorus content obtained by digesting the perchloric acid "soil-residue" with hydrofluoric acid shows that perchloric acid is very efficient in removing total "reserve" phosphorus from the Kingfisher No. 1 profile (Table XXI, Part II). When reported on a percentage basis, perchloric acid is from 90.0-100.0% efficient in the removal of total "reserve" phosphorus from this soil (Table XXII).

TABLE XX

MECHANICAL ANALYSIS - KINGFISHER No. 1

	Percentage of each size separate*				
Horizon	Coarse-fine sand	Very fine sand	Silt (all)	Clay (all)	Total
A_1	2.35	23.07	53.22	18.21	96.85
B1	2.05	16.65	43.81	33.72	96.23
B_{2-1}	2.23	13.40	41.45	39.58	96.66
B_{2-2}	1.67	9.64	53.11	32.39	96.71
B_3	0.36	5.41	61.24	30.32	97.33
C_1	0.15	3.50	64.54	28.01	96.20
C_2	0.14	3.92	65.95	26.38	96.39
C_3	0.68	4.19	66.82	22.74	94.43

* The percentages are corrected to account for weight loss due to organic matter oxidation.

TABLE XXI - KINGFISHER No. 1

PPM OF TOTAL "RESERVE" PHOSPHORUS OBTAINED FROM:

	PART I			PART II		
	Mechanical separates			Whole soil		
Horizon	$HClO_4$ Digest.	HF Digest.	Total*	$HClO_4$ Digest.	HF Digest.	Total*
A_1	99.9	3.0	102.9	340.0	----	340.0
B_1	128.4	5.9	134.3	240.0	4.2	244.2
B_{2-1}	111.3	4.1	115.4	176.0	8.0	184.0
B_{2-2}	103.7	3.1	106.8	200.0	20.0	220.0
B_3	98.2	3.1	101.3	270.0	----	270.0
C_1	104.6	3.8	108.4	306.0	10.8	316.8
C_2	103.4	1.9	105.3	348.0	6.8	354.8
C_3	67.2	2.2	69.4	336.0	4.0	340.0

* PPM of total phosphorus from perchloric acid digestion plus the PPM of total phosphorus from hydrofluoric acid digestion is reported as total "reserve" phosphorus.

TABLE XXII - KINGFISHER No. 1

COMPARATIVE EFFICIENCY OF THE REMOVAL OF TOTAL PHOSPHORUS BY TWO METHODS OF DIGESTION

	Percent of total phosphorus removed from the whole soil by:	
Horizon	Perchloric acid	Hydrofluoric acid*
A_1	100.0	----
B_1	98.3	1.7
B_{2-1}	95.7	4.3
B_{2-2}	90.9	9.1
B_3	100.0	----
C_1	96.6	3.4
C_2	98.1	1.9
C_3	98.8	1.2

* Digestion of the residue left from the perchloric acid digestion with 48% hydrofluoric acid.

Digestion of the soil separates with perchloric acid removes practically all of the total "reserve" phosphorus from the coarse-fine sand, very fine sand, and silt separates (Table XXIII), but fails to remove all of the phosphorus from the clay as shown by the total phosphorus removed from the perchloric acid "soil-residue" by hydrofluoric acid digestion (Table XXIV). The ratios reported in Table XXV show the relationship of total phosphorus removed by digesting the soil separates with perchloric acid as compared to the total phosphorus removed by digesting the remaining residue with hydrofluoric acid.

The amounts of total phosphorus the soil separates contribute to the whole soil when digested with perchloric acid and hydrofluoric acid are shown in Tables XXVI and XXVII.

TABLE XXIII - KINGFISHER No. 1

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand*	Very fine sand	Silt	Clay
A_1	----	44.8	37.6	376.0
B_1	----	40.4	38.8	308.0
B_{2-1}	----	43.6	34.4	228.0
B_{2-2}	----	48.0	46.4	228.0
B_3	----	48.8	52.8	208.0
C_1	----	58.7	51.2	248.0
C_2	----	53.3	51.2	256.0
C_3	----	94.7	49.6	144.0

* All of the sand separates were analyzed together because of the small quantity of coarse-fine sand separates.

TABLE XXIV - KINGFISHER No. 1

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay
A_1	----	----	----	16.2
B_1	----	----	----	17.4
B_{2-1}	----	----	----	10.3
B_{2-2}	----	----	----	9.7
B_3	----	----	----	10.3
C_1	----	8.3	----	13.6
C_2	----	----	----	7.1
C_3	----	3.3	----	9.2

* Residue left from the perchloric acid digestion is redigested with 48% hydrofluoric acid.

TABLE XXV - KINGFISHER No. 1

RELATIONSHIP OF PHOSPHORUS REMOVED BY PERCHLORIC ACID AND HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Combined sands	Silt	Clay
A_1	----	----	----	----	23.2
B_1	----	----	----	----	17.7
B_{2-1}	----	----	----	----	22.1
B_{2-2}	----	----	----	----	23.5
B_3	----	----	----	----	20.2
C_1	----	7.1	7.1	----	18.2
C_2	----	----	----	----	36.1
C_3	----	28.7	28.7	----	15.7

* The numbers represent the ratio of PPM of phosphorus removed by perchloric acid digestion to the PPM of phosphorus removed by hydrofluoric acid digestion. A narrow ratio indicates minimum phosphorus removal by perchloric acid digestion.

TABLE XXVI - KINGFISHER No. 1

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand*	Very fine sand	Silt	Clay	Total	Whole soil**
A_1	----	11.4	20.0	68.5	99.9	340.0
B_1	----	7.6	17.0	103.9	128.4	240.0
B_{2-1}	----	6.8	14.3	90.2	111.3	176.0
B_{2-2}	----	5.4	24.6	73.6	103.7	200.0
B_3	----	2.8	32.3	63.1	98.2	270.0
C_1	----	2.1	33.0	69.5	104.6	306.0
C_2	----	2.2	33.8	67.5	103.4	348.0
C_3	----	4.6	33.1	32.5	67.2	336.0

* All of the sand separates were analyzed together because of the small quantity of coarse-fine sand separates.

** The figures in this column represent total phosphorus in the soil before removal of organic matter and before mechanical separations were made.

TABLE XXVII - KINGFISHER No. 1

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay	Total	Soil residue**
A_1	----	----	----	3.0	3.0	----
B1	----	----	----	5.9	5.9	4.2
B2-1	----	----	----	4.1	4.1	8.0
B_{2-2}	----	----	----	3.1	3.1	20.0
B_3	----	----	----	3.1	3.1	----
C_1	----	----	----	3.8	3.8	10.8
C_2	----	----	----	1.9	1.9	6.8
C_3	----	0.1	----	2.1	2.2	4.0

* Data were obtained by multiplying PPM of phosphorus from hydrofluoric acid digestion times the percent of each separate for the corresponding horizon.

** The residue left from perchloric acid digestion of the whole soil is redigested with 48% hydrofluoric acid.

Kingfisher No. 2.

Available phosphorus content of the different horizons of this soil is very low, but there is almost as much available phosphorus in the lowest horizon as the A_{1-1} horizon (Table XXVIII). Also, the distribution

TABLE XXVIII - KINGFISHER No. 2

DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS*

Horizon	PPM Phosphorus
A1-1	3.3
A_{1-2}	2.4
A_3	1.7
B_{2-1}	1.3
B_{2-2}	1.6
B_3	2.1
C_1	1.5
C_2	2.1

* Extracted with 0.03N NH_4F + 0.025N HCl, 1:7 soil solution ratio for one minute.

of available phosphorus with profile depth is almost parallel with the total "reserve" phosphorus distribution pattern (Figure 4).

The mechanical analysis for Kingfisher No. 2 is reported in Table XXIX.

Figure 4 - Kingfisher No. 2

COMPARISON OF THE DISTRIBUTION OF TOTAL PHOSPHORUS AND DILUTE FLUORIDE-DILUTE ACID SOLUBLE PHOSPHORUS

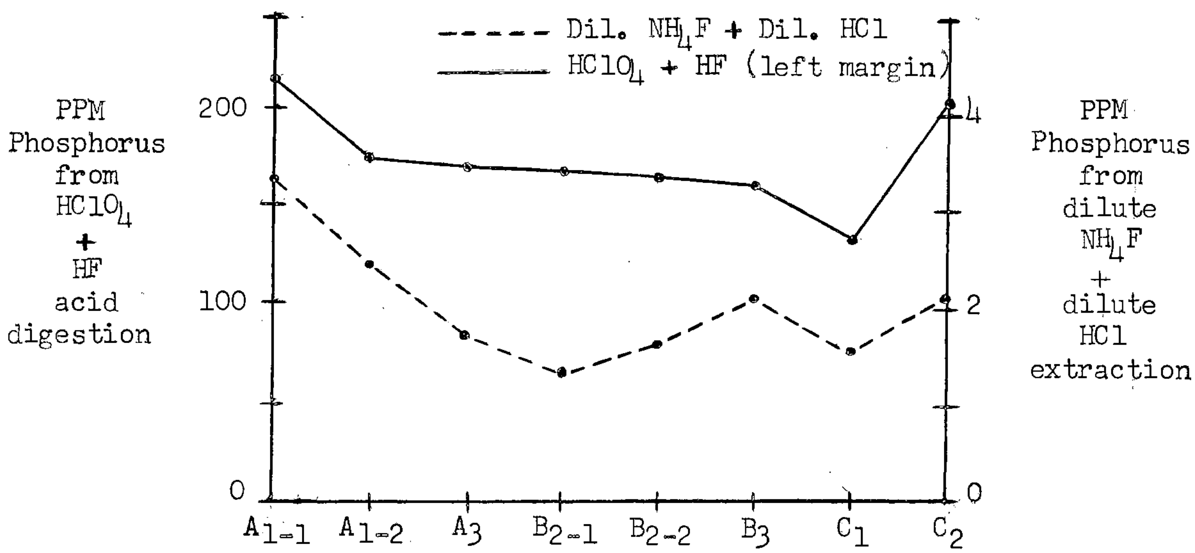


TABLE XXIX

MECHANICAL ANALYSIS - KINGFISHER No. 2

	Percentage of each size separate*				
Horizon	Coarse-fine sand	Very fine sand	Silt (all)	Clay (all)	Total
A_{1-1}	0.76	29.19	56.26	12.66	98.87
A_{1-2}	0.85	27.48	52.60	17.04	97.97
A_3	0.96	25.17	52.74	18.88	97.75
B_{2-1}	0.80	23.82	45.58	27.59	97.79
B_{2-2}	0.69	22.40	46.62	28.10	97.81
B_3	0.48	22.67	52.32	22.87	98.34
C_1	0.52	23.21	57.42	17.93	99.08
C_2	0.90	23.90	52.31	19.30	96.41

* The percentages are corrected to account for weight loss due to organic matter oxidation.

Total phosphorus removed from the whole soil by perchloric acid digestion is uniformly distributed throughout the profile of Kingfisher No. 2 (Table XXX, Part II). Digestion of the perchloric acid "soil-residue" with hydrofluoric acid indicates that perchloric acid is very efficient in removing total "reserve" phosphorus (Table XXX, Part II). When reported on a percentage basis the perchloric acid is shown to be from 90.6-100.0% efficient in removing total "reserve" phosphorus from this soil (Table XXXI).

TABLE XXX - KINGFISHER No. 2

PPM OF TOTAL "RESERVE" PHOSPHORUS OBTAINED FROM:

	PART I			PART II		
	Mechanical separates			Whole soil		
Horizon	$HClO_4$ Digest.	HF Digest.	Total*	$HClO_4$ Digest.	HF Digest.	Total*
A_{1-1}	57.3	2.3	59.6	216.0	----	216.0
A_{1-2}	69.9	2.6	72.5	176.0	----	176.0
A_3	96.2	3.1	99.3	162.4	8.8	171.2
B_{2-1}	121.8	3.9	125.7	156.0	16.2	172.2
B_{2-2}	107.8	4.0	111.8	156.0	12.2	168.2
B_3	112.1	2.3	114.4	152.0	11.4	163.4
C_1	72.4	1.0	73.4	136.0	----	136.0
C_2	75.0	1.2	76.2	196.0	12.0	208.0

* PPM of total phosphorus from perchloric acid digestion plus the PPM of total phosphorus from hydrofluoric acid digestion is reported as total "reserve" phosphorus.

In the Kingfisher No. 2 profile all of the total "reserve phosphorus is removed from the combined sands and silt separates by perchloric acid digestion (Table XXXII), but some phosphorus still remains in the clay residue (Table XXXIII). The total phosphorus which remains in the clay after perchloric acid digestion is probably due to the presence of highly insoluble aluminum phosphate compounds or by the substitution of phosphorus for some of the aluminum or hydroxyl ions in the crystal lattice or both.

The ratios reported in Table XXXIV show the relationship of total phosphorus removed by digesting the soil separates with perchloric acid as compared to the total phosphorus removed from the remaining residue by hydrofluoric acid digestion. The amounts of total phosphorus the soil separates contribute to the whole soil by perchloric acid and hydrofluoric acid digestion are shown in Tables XXXV and XXXVI.

TABLE XXXI - KINGFISHER No. 2

COMPARATIVE EFFICIENCY OF THE REMOVAL OF TOTAL PHOSPHORUS BY TWO METHODS OF DIGESTION

	Percent of total phosphorus removed from the whole soil by:	
Horizon	Perchloric acid	Hydrofluoric acid*
A_{1-1}	100.0	----
A_{1-2}	100.0	----
A_3	94.9	5.1
B_{2-1}	90.6	9.4
B_{2-2}	92.7	7.3
B_3	93.0	7.0
C_1	100.0	----
C_2	94.2	5.8

* Digestion of the residue left from the perchloric acid digestion with 48% hydrofluoric acid.

TABLE XXXII - KINGFISHER No. 2

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand*	Very fine sand	Silt	Clay
A_{1-1}	----	36.0	37.6	200.0
A_{1-2}	----	42.0	42.8	208.0
A_3	----	46.4	42.0	328.0
B_{2-1}	----	48.8	47.2	320.0
B_{2-2}	----	48.0	43.6	272.0
B_3	----	51.2	41.2	344.0
C_1	----	35.2	40.4	228.0
C_2	----	39.6	42.0	224.0

* All of the sand separates were analyzed together because of the small quantity of coarse-fine sand separates.

TABLE XXXIII - KINGFISHER No. 2

PPM OF TOTAL PHOSPHORUS REMOVED FROM THE MECHANICAL SEPARATES BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay
A_{1-1}	----	----	----	18.1
A_{1-2}	----	----	----	15.3
A_3	----	----	----	16.6
B_{2-1}	----	----	----	14.0
B_{2-2}	----	----	----	14.2
B_3	----	----	----	9.9
C_1	----	----	----	5.6
C_2	----	----	----	6.2

* Residue left from the perchloric acid digestion is redigested with 48% hydrofluoric acid.

TABLE XXXIV - KINGFISHER No. 2

RELATIONSHIP OF PHOSPHORUS REMOVED BY PERCHLORIC ACID AND HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Combined sands	Silt	Clay
A_{1-1}	----	----	----	----	11.0
A_{1-2}	----	----	----	----	13.6
A_3	----	----	----	----	19.8
B_{2-1}	----	----	----	----	22.9
B_{2-2}	----	----	----	----	19.2
B_3	----	----	----	----	34.7
C_1	----	----	----	----	40.7
C_2	----	----	----	----	36.1

* The numbers represent the ratio of PPM of phosphorus removed by perchloric acid digestion to the PPM of phosphorus removed by hydrofluoric acid digestion. A narrow ratio indicates minimum phosphorus removal by perchloric acid digestion.

TABLE XXXV - KINGFISHER No.2

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY PERCHLORIC ACID DIGESTION

Horizon	Coarse-fine sand*	Very fine sand	Silt	Clay	Total	Whole soil**
A_{1-1}	----	10.8	21.2	25.3	57.3	216.0
A_{1-2}	----	11.9	22.5	35.4	69.9	176.0
A_3	----	12.1	22.2	61.9	96.2	162.4
B_{2-1}	----	12.0	21.5	88.3	121.8	156.0
B_{2-2}	----	11.1	20.3	76.4	107.8	156.0
B_3	----	11.9	21.6	78.7	112.1	152.0
C_1	----	8.4	23.2	40.9	72.4	136.0
C_2	----	9.8	22.0	43.2	75.0	196.0

* All the sand separates were analyzed together because of the small quantity of coarse-fine sand separates.

** The figures in this column represent total phosphorus in the soil before removal of organic matter and before mechanical separations were made.

TABLE XXXVI - KINGFISHER No. 2

PPM OF TOTAL PHOSPHORUS THE MECHANICAL SEPARATES CONTRIBUTE TO THE WHOLE SOIL BY HYDROFLUORIC ACID DIGESTION*

Horizon	Coarse-fine sand	Very fine sand	Silt	Clay	Total	Soil residue**
A_{1-1}	----	----	----	2.3	2.3	----
A_{1-2}	----	----	----	2.6	2.6	----
A_3	----	----	----	3.1	3.1	8.8
B_{2-1}	----	----	----	3.9	3.9	16.2
B_{2-2}	----	----	----	4.0	4.0	12.2
B_3	----	----	----	2.3	2.3	11.4
C_1	----	----	----	1.0	1.0	----
C_2	----	----	----	1.2	1.2	12.0

* Data were obtained by multiplying PPM of phosphorus from hydrofluoric acid digestion times the percent of each separate for the corresponding horizon.

** The residue from perchloric acid digestion of the whole soil is redigested with 48% hydrofluoric acid.

DISCUSSION

Available phosphorus is low in the Zaneis and Kingfisher profiles studied (Tables I, X, XIX, and XXVIII). However, distribution of available phosphorus with profile depth suggests that there is a greater phosphorus "reserve" in the lower horizons or the phosphorus is more easily available in the Kingfisher profiles as compared to the Zaneis profiles.

Total phosphorus removed from the whole soil by perchloric acid digestion is about the same order of magnitude for the two Zaneis profiles, but is not as great as the phosphorus content of the two Kingfisher profiles (Part II of Tables II, XII, XXI, and XXX). There is considerable variation between the two Kingfisher profiles with respect to the amounts of total "reserve" phosphorus removed by perchloric acid digestion. However, there is very little difference between the two Kingfisher profiles in efficiency of phosphorus removed from the perchloric acid "soil-residue" by hydrofluoric acid digestion. When the phosphorus removed from the Zaneis and Kingfisher profiles by perchloric acid digestion is reported on a percentage basis it can be shown that the phosphorus in the Kingfisher is not held as strongly as the phosphorus in the Zaneis. Perchloric acid is 90.9-100.0% efficient in the removal of total "reserve" phosphorus from the Kingfisher No. 1 and 90.6-100.0% efficient for Kingfisher No. 2 as compared to 20.7-87.2% efficiency for Zaneis No. 1 and 57.0-93.0% efficiency for Zaneis No. 2 (Tables XXII, XXXI, VII, and XVI).

Total phosphorus removed from the respective soil separates by perchloric acid digestion appears to be about the same for the four profiles studied (Tables IV, XIII, XXIII, and XXXII). However, there is a noticeable difference in the amount of total phosphorus removed by hydrofluoric acid digestion of the remaining residues of the Zaneis soil separates as compared to the Kingfisher soil separates (Tables V, XIV, XXIV, and XXXIII). Generally, more phosphorus remains in the respective sand, silt, and clay residues of the two Zaneis profiles after perchloric acid digestion than in the two Kingfisher profiles. In all four profiles there is less total "reserve" phosphorus removed by hydrofluoric acid digestion as the degree of weathering increases, but this decrease in phosphorus removal is more pronounced in the Kingfisher profiles than in the Zaneis profiles. Although some phosphorus still remains in the clay residues of all four soils after perchloric acid digestion, this phosphorus is removed more easily from the Kingfisher as compared to the Zaneis clay separates according to the ratios reported in Tables VI, XV, XXV, and XXXIV.

SUMMARY AND CONCLUSIONS

Two Zaneis and two Kingfisher soils were selected for this study. The whole soil was analyzed for available phosphorus by the Bray and Kurtz method and total phosphorus was determined in the whole soil and mechanical separates by perchloric acid digestion. Total "reserve" phosphorus in the residues remaining was removed by hydrofluoric acid digestion.

Both soils are low in available phosphorus, but distribution of available phosphorus is more uniform with profile depth in the Kingfisher soils as compared to the Zaneis soils.

Total "reserve" phosphorus in both soils is relatively low. However, there is considerable difference in the phosphorus distribution within the two soils with respect to profile depth. Apparently the total "reserve" phosphorus in the lower horizons of the Zaneis profiles has already been utilized by plants or else the parent material was inherently low in phosphorus. The relatively high total "reserve" phosphorus content of the lower horizons of the Kingfisher soil partially accounts for the greater phosphorus supplying ability and lack of phosphatic fertilizer response of the Kingfisher soils as compared to the Zaneis. Also, the phosphorus is not held as strongly by the soil in the Kingfisher profiles as shown by the comparative efficiency of phosphorus removal by perchloric acid digestion.

Analysis of the mechanical separates shows that the clay is much richer in total "reserve" phosphorus than any of the other soil separates and this phosphorus is more easily removed by perchloric acid digestion than the phosphorus held in the coarser sand separates. The perchloric acid phosphorus removal-particle size relationship probably accounts for the greater difficulty exhibited in removing total "reserve" phosphorus from the Zaneis profiles since these soils are much higher in coarse sand than the Kingfisher profiles.

LITERATURE CITED

1. Aldrich, D. G. and Buchanan, J. R. Phosphorus content of soils and their parent rocks. Soil Sci. 77:369-376. 1954.

2. Allaway, W. H. and Rhoades, H. F. Forms and distribution of phosphorus in the horizons of some Nebraska soils in relation to profile developement. Soil Sci. 72:119-128. 1951.

3. Bray, R. H. and Dickman, S. R. Adsorbed phosphates in soils and their relations to crop response. Soil Sci. Soc. Amer. Proc. 6: 312-320. 1941.

4. __________. and Kurtz, L. T. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39-45. 1945.

5. Byers, H. G., Alexander, L. T., and Holmes, R. J. The composition of the colloids of certain of the Great Soil Groups. U.S. Dept. Agr. Tech. Bul. 484. 1935.

6. Caldwell, A. C. and Rost, C. O. The chemical composition of the clay fractions of the Black Prairie soils of Minnesota. Soil Sci. 53: 249-263. 1942.

7. Godfrey, C. L. and Riecken, F. F. Distribution of phosphorus in some genetically related loess-derived soils. Soil Sci. Soc. Amer. Proc. 18:80-84. 1954.

8. Harper, H. J. Methods for the analysis of soil and plant materials. Soils Lab., Oklahoma Agr. and Mech. College, Stillwater, Oklahoma. 1948.

9. Millar, C. E. Soil Fertility. John Wiley and Sons, Inc., New York, N. Y. p. 139. 1955.

10. Piper, C. S. Soil and Plant Analysis. The University of Adelaide, Adelaide, Australia. p. 75. 1942.

11. Robinson, W. O. and Holmes, R. S. The chemical composition of soil colloids. U.S. Dept. Agr. Bul. 1311. 1924.

12. Stout, P. R. Alterations in crystal structure of clay minerals as a result of phosphorus fixation. Soil Sci. Soc. Amer. Proc. 4:177-182. 1939.

13. Tanner, C. B. and Jackson, M. L. Nomographs of sedimentation times for soil particles under gravity or centrifigul acceleration. Soil Sci. Soc. Amer. Proc. 12:60-65. 1947.

14. Williams, E. G. and Saunders, W. M. H. Distribution of phosphorus in profiles and particle size fractions of some Scottish soils. Journ. Soil Sci. 7:90-108. 1956.

15. ________________. Significance of particle-size fractions in readily soluble phosphorus extractions by the Acetic, Truog, and Lactate methods. Journ. Soil Sci. 7:No. 2. 189-202. 1956.

APPENDIX

PROFILE DESCRIPTIONS OF THE SOILS USED FOR THIS STUDY

ZANEIS LOAM No. 1.

The soil sample was collected 2 miles east and 2 miles north of Stillwater, Oklahoma, 950 feet west of the North Quarter corner or 1782 feet east of the northwest corner of Section 7, Township 19 North, Range 3 East. The sample was taken from a native hay meadow composed mostly of tall grasses, with an adjoining cultivated field to the east. The site is in normal erosional upland with a convex surface and slope gradient of about 2 percent.

A_1	0-9 inches	Dark brown (7.5 YR 4/2, 3/2, m.) loam or silt loam; moderate medium granular; friable; porous; roots abundant; pH 5.9; grades to horizon below.
B_1	9-15 inches	Dark reddish-brown (5 YR 3/3) clay loam; weak subangular blocky; friable; permeable; pH 5.6; roots abundant; grades to horizon below.
B_2	15-24 inches	Dark reddish-brown (5 YR 3/3, 2/3, m.) heavy clay loam; weak subangular blocky; more clayey than horizon above; moderately friable; permeable; pH 5.8; porous; roots abundant; some fine ferruginous concretions; grades to horizon below.
B_3	24-36 inches	Reddish-brown (5 YR 4/3, 3/3, m.) sandy clay loam; mottled with yellowish-red (5 YR 4/6); weak subangular blocky; friable; porous; moderately permeable; few ferruginous concretions; roots abundant pH 6.0.
C	36-46 inches	Reddish-brown sandy clay loam with seams of weathered sandstone; weakly stratified with heavier clayey material; pH 6.1.
D	46 inches +	Dark reddish-brown (2.5 YR 3/4) well indurated sandstone; very slightly friable; pH 6.2.

The parent material developes in thinly bedded sandy rocks of the Chase group of the Wellington formation which is here composed of alternating bands of sandstone and clays.

ZANEIS LOAM No. 2.

The soil sample was taken from a site 1 1/2 miles west of the Oklahoma State University Dairy Barn, 1520 feet east of the southwest corner of Section 8, Township 19 North, Range 2 East. The sample was from a native tall grass prairie area, weak convex slope with a two percent gradient.

A_1	0-11 inches	Very dark reddish-gray (5 YR 4/2, 3/2, m.) loam or silt loam; moderate medium granular; porous; friable; permeable; roots abundant; pH 6.0; grades to horizon below.
B_1	11-23 inches	Yellowish-red (5 YR 4/2, 3/4, m.) clay loam; prismatic to weak subangular blocky; friable; permeable; porous; roots abundant; pH 5.6.
B_{2-1}	23-32 inches	Yellowish-red (5 YR 5/6, 3/4, m.) silty clay loam; structure same as above; very hard dry; pH 5.8.
B_{2-2}	32-42 inches	Dark reddish-brown (5YR 3/4, m., 4/6, crushed d.) silty clay loam; structure same as above; few ferruginous concretions; pH 5.9.
B_{3-1}	42-48 inches	Yellowish-red (5 YR 5/6, 4/6, m.) sandy clay; stratas of soft weathered sandstone; more iron concretions than above; weak subangular blocky; pH 6.0.
B_{3-2}	48-58 inches	Dark red (2.5 YR 3/6) weak subangular blocky; iron concretions increase with depth; some stratified layers of rather raw shale and weathered sandstone; pH 6.1.
C	58-78 inches	Dark reddish-brown (2.5 YR 4/4, 3/4, m.) definitely weathered sandstone and shale; pH 6.3.

KINGFISHER No. 1.

A soil sample was taken 2 miles east of the main corners in the city of Kingfisher, Oklahoma, on state highway 33, 1500 feet east of the northwest corner of Section 24, Township 16 North, Range 7 West. The site is in a native grass pasture dominantly of short and mid grasses including buffalo, blue grama, side oats grama, and scattered clumps of little bluestem. The slope is weak convex with 1 1/2-2 percent gradient.

A_1	0-10 inches	Brown (7.5 YR 4/3, 3/3, m.) silt loam; moderate medium granular; friable; a few fine pores; abundant fine roots; pH 6.3; grades to horizon below.
B_1	10-14 inches	Reddish-brown (5 YR 4/3, 3/3, m.) silty clay loam; strong medium subangular blocky; firm; a few holes, worm casts, and pores; pH 6.2; grades to horizon below.
B_{2-1}	14-21 inches	Reddish-brown (2.5 YR 4/4, 3/4, m.) silty clay loam; compound moderate medium prismatic and strong coarse subangular blocky; firm; very hard dry; continuous clay films on peds which are about 1 value darker than interiors; roots are well distributed along the prisms and through the peds; pH 6.3; grades through a 3-inch transition to the horizon below.
B_{2-2}	21-32 inches	Reddish-brown (5 YR 4/4) silty clay loam with a few small red spots; compound moderate medium prismatic and moderate coarse subangular blocky; very firm; very hard when dry; pH 6.3; sides of peds have dark reddish-brown clay film coatings which are 1 value darker than the interiors; grades to horizon below.
B_3	32-42 inches	Yellowish-red (5 YR 4/6, 5/6, crushed) silty clay loam; with structure like the horizon above; sides of peds are slightly coated with dark reddish-brown films; a few soft black films; very firm; very hard dry; pH 6.4; grades indistinctly to horizon below.
C_1	42-52 inches	Red (3.5 YR 5/6, 4/6, m.) heavy silty clay loam; compound weak medium prismatic and weak blocky; very firm; very hard dry; a few very fine pores; pH 6.8; grades shortly to horizon below.
C_2	52-65 inches	Red (3.5 YR 5/6, 4/6, m.) heavy silty clay loam; weak medium blocky; about like the C_1 horizon but has a few white sandy grains in the mass; non-calcareous; pH 7.0; grades to horizon below.
C_3	65-74 inches+	Red (3.5 YR 5/6) silty clay loam with seams of fine grained noncalcareous sandstone about 1/8 inch thick; a thicker band of this flat-bedded sandstone limits further digging at 74 inches; pH 7.0.

This parent material is formed from the Cedar Hills sandstone member of the Hennessey formation. Roots are well distributed in all layers down to and including the C_1. Below this the roots are sparse and occur only in natural cracks.

KINGFISHER No. 2.

The sample was taken ½ mile west of Okarche, Oklahoma, in the SE SE NE ¼ of Section 36, Township 13 North, Range 8 West, in a native pasture mostly of short and mid grasses. The slope is weak convex with a 1½ percent gradient.

A_{1-1}	0-7 inches	Reddish-brown (5 YR 4/4, 3/4, m.) silt loam; moderate medium granular; friable; permeable; pH 6.0; grades to.
A_{1-2}	7-14 inches	Same as above except the structure is slightly stronger; pH 6.2; this grades through a 2-inch transition to the horizon below.
A_3	14-19 inches	Reddish-brown (5 YR 4/4, 3/4, m.) heavy silt loam; moderate medium granular; friable; numerous pores and fine root holes; pH 6.4; grades to horizon below.
B_{2-1}	19-28 inches	Reddish-brown (2.5 YR 4/5, 3/5, m.) silty clay loam; moderate medium subangular blocky; firm; weak clay films on peds which are darker than interiors; pH 6.5; grades to horizon below.
B_{2-2}	28-36 inches	Reddish-brown (2.5 YR 4/4, 3/4, m.) heavy silty clay loam; compound coarse prismatic and weak medium blocky; firm; slowly permeable; pH 6.6; clay films apparent; surfaces darker than interiors; grades to horizon below.
B_3	36-44 inches	Red (2.5 YR 4/6, 3/6, m.) silty clay loam; much like the horizon above but without the clay films; a few black spots and partly weathered sandstone fragments; pH 6.6; grades to horizon below.
C_1	44-56 inches	Red (2.5 YR 4/8, 3/8, m.) heavy loam between the seams of slightly hardened fine grained sandstone; slightly of indistinctly laminated with silty strata; pH 6.7; changes slightly to the easier digging, less hard layer below.

C_2	56-68 inches	Heavy silty clay loam which is of slightly hardened silty rocks; this rests on a thicker, hardened layer of sandstone at 68 inches which prohibits further digging; pH 7.1.

There is good root distribution through the B_{2-2}. Below this the roots are smaller, less abundant, and occupy only the natural cracks between peds.

The parent material is weathered from the Cedar Hills sandstone member of the Hennessey formation.

VITA

Daryl Davis

candidate for the degree of

Master of Science

Thesis: A study of the distribution of total phosphorus in the mechanical separates of two similar Reddish Prairie soil profiles.

Major: Soils

Biographical:

Personal data: Born October 8, 1933, at Lone Wolf, Oklahoma, the son of Fred and Floy Ellen Davis.

Education: Attended elementary school at Soldiers Spring, near Lone Wolf, Oklahoma. Graduated from Lone Wolf High School, Lone Wolf, Oklahoma, in 1951. Received the Bachelor of Science degree from Oklahoma Agricultural and Mechanical College with a major in Soil Science, May, 1955. Graduate study at Oklahoma State University, September, 1957 to January, 1959.

Experience: Reared on a farm, U.S. Army 3rd Inf. Div., Ft. Benning, Georgia, 1956. Graduate Assistant at Oklahoma State University, 1957-1958.

Organizations: Member of the Agronomy Club, Alpha Zeta, and Circle Eight Square Dance Club.

Date of Final Examination: January, 1959.