THE EFFECT OF NITROGEN, PHOSPHORUS AND POTASSIUM ON THE GROWTH OF WHEAT ON SOME SOILS OF SALINE COUNTY, KANSAS

by

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INTRODUCTION

Field work on a detailed, basic soil survey for Saline county was completed in the fall of 1949. The soil map, yield data, opinions, and experiences of agricultural workers in Saline county clearly indicated that there were certain low-fertility agricultural soils which might be studied profitably under greenhouse conditions.

A greenhouse soil fertility study of 10 soils from Saline county and 4 soils from Jackson county was initiated during the fall of 1949. The study was limited to those soils which, in the opinion of the county agent and other agricultural workers in Saline and Jackson counties, represented significant acreages and common fertility problems. The Jackson county soils were included in the experiment because they were known by the writer to offer no special fertility problems. It was thought that the yield results from these soils would afford a satisfactory means for comparing and evaluating the yields obtained from the Saline county soils.

The objective of the experiment was to determine whether these soils, when cropped to wheat, would respond to applications of nitrogen, phosphorus, and potassium fertilizer materials. If responses were noted, an attempt would be made to evaluate the magnitude of response.

REVIEW OF LITERATURE

In 1949, Brown and Olson (3) reported work on some of the more important Saline county soils with special emphasis on the catena relationships involved. As a result of their studies, several catena groupings evolved, based on parent material, chemical and physical analysis. They grouped the soils studied into three separate catenas: the Wellington Formation Catena, the Minnescah Shale Catena, and the Quaternary Loess Catena. The Quaternary Loess Catena includes: Elmo silt loam, Berg silt loam, and Lockard silt loam--all of which are important soils studied in this experiment.

Elmo soils are deep, friable, noncalcareous soils which have developed on undulating portions of the upland. These soils occur on normal topography and are characterized by dark surface soils, reddish brown subsoils, and brown friable parent materials. There is no free lime within the upper four feet of the profile.

Berg soils are deep claypan soils which have developed on low undulating hills adjacent to areas of the Elmo soils. Such soils occur on areas somewhat more flat than normal topography and are characterized by dark surface soils, brown, hard claypan subsoils, and brown, friable, silty clay loam parent materials. Lime occurs in the B_2 horizon.

Lockard soils are deep claypan soils which have developed on level to very gently sloping upland flats. They have dark, friable, silty surface soils, brown, hard, blocky, silty clay subsoils, and alkaline but noncalcareous parent materials.

In November 1950, Cline[1] reported the following catena groupings for the Saline county soils studied in this experiment:

> Berg, Ebenezer, Niles catena. This is a complete catena grouping, ranked in order of degree of profile development. These soils are developing in silty parent materials that have been identified as loess of Peorian age.
>
> Lockard, Rokeby catena. It has been tentatively postulated that the parent material from which these soils are developing is Peorian Loess. It has been altered subsequent to deposition and prior to soil development by being subjected to anerobic conditions such as might occur in shallow lakes or areas of extremely high and continuous water tables.
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> Edalgo catena. The Edalgo soils are lithosols developing from the soft clay shales of the Kiowa formation. It is the most common soil of this catena.
>
> Lancaster catena. The Lancaster series is the important member of the catena of soils developing on Kiowa sandstone and shale.
>
> Elmo catena. The Elmo series represents the most important member of the catena developing from what is thought to be loess deposits of Loveland age. More

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[1]Arvad J. Cline, unpublished work presented to author in personal communication.

properly, these parent materials may represent an intermixture of Loveland silts, clays, talus, and outwash materials from the eroding high plains escarpments. Geologists fix the tentative age of these materials as of Loveland time. The Elmo series is the most immature of the group.

Cline, in unpublished work, described all of the soils which were involved in this study and indicated some of the more important considerations pertaining to each soil.

Berg Series. The Berg series consists of greyish-brown, deep claypan soils. They are developing on low, undulating hills in and bordering old geologic terraces and drainageways. The parent material is fine textured, brown to greyish-brown, loess-like deposits.

These soils are characterized by very dark-brown, friable, slightly acid, silty surface soils; dark greyish-brown to brown, hard claypan subsoils; and brown to greyish-brown, friable, silty-clay loam parent materials. These soils have a well-developed lime horizon and overlay loess-like beds of neutral to slightly alkaline reaction.

Slope character for this unit is uniform and consists of moderately sloping, convex ridges and hillsides usually lying within or bordering on old established terraces.

The Berg series is one of the most important agricultural soils in Saline county. These soils are used for wheat, alfalfa, sweet clover, corn, and sorghum. Yield records indicate that these soils have an average wheat yield of 13.9 bushels per acre over a 10-year period. Evidence exists that these soils will respond consistently to phosphatic fertilizers, but the degree of response is less than in some of the other upland soil types.

Ebenezer Series. The Ebenezer series consists of greyish-brown planosolic soils. These soils are developing on upland slopes and ridges from mottled pale-brown, silty parent material believed to be of aeolian origin. These deposits are several feet in thickness and rest on Cretaceous or Permian shales.

The Ebenezer soils have dark-grey granular surface soils underlaid by greyish-brown, granular, A_2 horizons. The soil aggregates are stained and flecked with light grey. They have greyish-brown, relatively thin but hard B horizons, which are underlaid by pale-brown, mottled, silty parent materials.

This series is found principally along upland ridges and slopes bordering major drainage channels. Slopes are moderately short, convex, and of moderate gradient.

Agriculturally, the Ebenezer series is one of the major soils of Saline county, but it is only moderately productive. It is used principally for wheat, sorghum, corn, alfalfa, and sweet clover. Yield records indicate that this soil has a 10 year average wheat yield of 9.0 bushels per acre. Field trials indicate that it will consistently show marked response to phosphatic fertilizer, accompanied by less response to nitrogenous fertilizer.

Edalgo Series. The Edalgo series includes friable soils of shallow to medium depth. These soils are developing residually on steeply sloping, convex ridge crests and shoulders from yellowish-grey to pale-yellow Dakota shales. Where observed, the shale beds underlying the soils are noncalcareous but, occasionally some members were found to be slightly calcareous. Interbedded soft sandstone occurs occasionally, but comprises a very small part of the parent materials.

The Edalgo soils have friable, weak-brown, moderately acid to strongly acid surface soil. The upper subsoils are weak-brown, friable, granular and moderately acid. The lower subsoils are dark-brown to moderate-brown, hard, faintly prismatic to very coarse granular or nuciform. The lower subsoil is usually found to be moderately acid.

Edalgo soils possess a low inherent fertility. Yield records indicate that this soil has an average yield of 6.4 bushels of wheat per acre. Field trials indicate that this soil responds very well to both phosphatic and nitrogenous fertilizers. When legumes are grown, an application of lime is necessary to secure a good stand.

Elmo Series. The Elmo series consists of brown to reddish-brown, deep, friable, noncalcareous, silty soils. These soils are developing from deep, friable, loess-like parent materials on undulating portions of the uplands. Normally, the Elmo soils have friable, granular, greyish-brown surfaces; brown to reddish-brown subsoils; and brown, friable parent materials. Free lime does not occur within the upper four feet; however, lime horizons have been observed six or seven feet below the ground surface.

Such a lime horizon is usually one to two feet in thickness and grades to noncalcareous material below.

Soils of the Elmo series are important agriculturally and are used principally for wheat, sorghum, corn, and forage crops. Yield records indicate that these soils have an average wheat yield of about 14 bushels per acre. This soil was reported to respond well to phosphatic and nitrogenous fertilizers.

Lancaster Series. The Lancaster series consists of deep, friable, mature soils. These soils are developing on parent materials weathered from noncalcareous sandstones of the Dakota formation. Normally, these soils occupy broad, gently sloping, convex ridge tops and slopes throughout the uplands.

Soils of this series are important agriculturally, especially in the western portion of Saline county. They are used principally for wheat, sorghum, corn and forage crops. Under virgin conditions, these soils support good native grass cover of blue grama, western wheat grass, and bluestem. The average wheat yield, based on a 10-year period, is 9 bushels per acre. These soils are reported to respond well to phosphatic and nitrogenous fertilizers. An application of lime is necessary to secure adequate stands of legumes.

Niles Series. The Niles series comprises deep, heavy claypan soils. These soils are developing from silty loess deposits on the top of undulating hills adjoining the junction of the uplands and major stream terraces. Surface soils are dark, friable, silt loam. The upper subsoil is weak-brown, friable, and granular.

The lower subsoil evidences a weakly-developed grey layer of heavy, dense silty clay loam. Parent materials are calcareous, moderate yellowish-brown, silt loam or silty clay loam.

Niles silt loam is used extensively for wheat, corn, sorghum, alfalfa, and sweet clover. Yield records indicate that this soil has a 10-year average wheat yield of 14.5 bushels per acre. Field trials indicate that this soil will respond to phosphatic fertilization. Some response has been noted from the use of nitrogenous fertilizer.

Lockard Series. The Lockard series consists of weak-brown claypan soils developing on old high terraces of geologic drainageways from moderate olive-brown, plastic alluvial clays. Soils of this series are characterized by dark, friable, silty surface soils; weak-brown, hard, blocky, clay subsoils; and moderate olive-brown alkaline, but not calcareous, parent materials.

The Lockard soils are some of the best upland wheat soils of the county. These soils have an average wheat yield over a 10-year period of about 16 bushels per acre. These soils have been observed to respond to phosphatic and nitrogenous fertilizers, but the degree of response is less for this soil than for some of the other associated types. Farmers have reported great difficulty in establishing lasting stands of alfalfa or sweet clover on these soils.

Rokeby Series. The Rokeby series consists of deep, very dark-colored, claypan soils. These soils are developing on nearly level stream terraces from fine textured, alluvial deposits.

Such soils have deep, dark, friable, noncalcareous topsoils; hard, blocky, noncalcareous subsoils; and deep, friable parent materials. Rokeby soils have slow internal and external drainage.

The Rokeby soils are fertile wheat soils and have a 10-year average wheat yield of about 16.5 bushels per acre. These soils are used for sorghums and corn. Farmers report no difficulty in establishing lasting stands of alfalfa. No consistent response to phosphatic or nitrogenous fertilizers has been reported for these soils.

The following soils are from Jackson county in Northeastern Kansas, described according to the Jackson County Reconnaissance Soil Conservation Survey (7):

Marshall, Carrington. These soils are deep, very dark soils with friable or moderately friable, silty to clayey subsoils. They are upland soils of the prairie zone, derived mainly from loess and glacial till.

Grundy, Sharpsburg, Pawnee. These soils are dark or very dark soils with tight clay or claypan subsoils. They are uplands of the prairie soil zone derived mainly from loess and glacial till.

Wabash, Judson-Wabash. These soils are very dark, or dark with friable or moderately friable, silty to clayey subsoils. These soils comprise most of the bottomlands of the area.

Buchard, Boone, Summit. These soils are moderately deep, dark or very dark soils with friable or moderately friable, silty to clayey subsoils. They are upland soils of the prairie soil zone derived from glacial till, sandstone, and limestone.

MATERIALS AND METHODS

Soil Sampling Procedure

The selection of sample sites, and the actual field sampling of the soils, was completed during the second week of November, 1949. Each soil was sampled in that portion of the county where it was known to occur in greatest acreage.

The profile of the soil at the sampling site was that which was considered to be normal for the soil. The areas selected for sampling were all cultivated fields. One hundred pound samples each of the surface soil and subsoil were taken from each location. A summary of the identifications of these soils is presented in Table 1.

Design of the Experiment

The fertility study was set up as a factorial design experiment (12). Applications of nitrogen, phosphorus, and potassium were made separately and in all possible combinations to each soil type under study. Table 2 illustrates the amount, kind, and combination of fertilizer carriers applied to each of eight pots for each soil type studied.

Greenhouse Procedure and Technique

All soil materials were thoroughly air dried in the greenhouse prior to screening. All materials were passed through a one-quarter inch screen to remove debris, rocks, and to reduce the size of excessively large clods.

Table 1. Identification of soils from Saline and Jackson counties, Kansas, used for greenhouse study.

Soil type	Parent material	Sampling location	Slope at sampling site
Berg silt loam	Peorian silt	220' E 60' S of NW corner Sec 4 T16S R3W	4
Ebenezer loam	Peorian silt	50' N 70' W of SE corner Sec 10 T14N R5W	3
Ebenezer silt loam	Peorian silt	820' E 80' S of NW corner Sec 6 T13S R2W	3
Edalgo silt loam	Cretaceous shales of Kiowa formation	300' S 300' E of N 1/4 corner Sec 30 T13S R4W	3
Elmo silt loam	Loveland silts, colluvial materials weathered from cretaceous deposits of Loveland time	100' E 100' S of W 1/4 corner Sec 3 T16S R5W	4
Lancaster loam	Cretaceous beds of Kiowa formation	1300' E 100' S of NW corner Sec 27 T13S R5W	3
Lancaster fine sandy loam	Cretaceous sandy shales and colluvial cretaceous material	1300' S 250' E of W 1/4 corner Sec 34 T13S R4W	4
Niles silt loam	Peorian silt	300' E 250' N of SW corner Sec 27 T16S R2W	1
Lockard silt loam	Peorian silt	800' N 150' W of E 1/4 corner Sec 15 T15S R3W	1/2

Table 1 (cont.).

Soil type	Parent material	Sampling location	Slope at Sampling site
Rokeby silt loam	Peorian silt	600' W 50' S of E 1/4 corner Sec 34 T15S R3W	1/2
*Marshall, Carrington	Loess, glacial till	2500' W 600' N of SE corner Sec 31 T5S R15E	3
*Grundy, Sharpsburg Pawnee	Loess, glacial till	1400' W 200' N of SE corner Sec 31 T5S R15E	3
*Wabash, Judson-Wabash	Stream bottom deposits	1300' N 200' W of SE corner Sec 5 T6S R15E	1
*Buchard, Boone Summit	Glacial till, sandstone, limestone	1300' W 200' N of SE corner Sec 5 T6S R15E	3

*Jackson county soils.

Table 2. The amount of fertilizer carrier applied to each soil type involved in the fertility study.

Treatment number	Soil treatments	Pounds per acre of fertilizer carrier applied per pot		
		NH_4NO_3	$CaH_4(PO_4)_2$	KCl
1	No treatment	--	--	--
2	N	800	--	--
3	P	--	1000	--
4	K	--	--	500
5	NP	800	1000	--
6	NK	800	--	500
7	PK	--	1000	500
8	NPK	800	1000	500

After screening, the fertilizer treatments were tabled into the 4,000 gram soil samples after which the soil was placed in one-gallon pots. One liter of water was added to each pot to thoroughly moisten the soil. Planting commenced as soon as the soil could be worked.

Fifteen kernels of spring wheat (Pusa 52 x Federation) were planted per pot. All pots were planted by December 18, 1949. Two weeks after emergence, all pots were thinned to 12 plants per pot.

Throughout the growth period of the wheat an attempt was made to maintain a daytime temperature of 75° to 80° F. and a night temperature of from 40° to 50° F.

No attempt was made to add a constant amount of water to each pot. Throughout the growth and maturity period of the plants, sufficient water was added to each pot to maintain what this worker considered an optimum moisture content.

Periodic spraying and dusting were necessary to control mildew, red spider, and aphids. It was found that flowers of sulphur dusted on the plants at weekly intervals effectively controlled mildew. Red spider and aphids were effectively controlled by the use of a liquid spray of Parathion.

Harvest commenced April 8, 1950. Pots receiving nitrogen and phosphorus, and nitrogen, phosphorus and potassium were first to mature. Harvest was extended over a two-weeks period until April 22, 1950. All plant material was oven dried before weighing.

Analytical Procedures

Determination of pH and Lime Requirement. Determination of soil pH (9) and lime requirement (13) was made on all soils under study. Ten grams of soil, to which 10 ml of water had been added, was allowed to stand for 30 minutes. The pH was determined by means of a Beckman pH meter. If the soil had a pH value less than 6.1, liming was regarded as being necessary. The lime requirement test was made by adding 20 ml of Woodruff's buffer solution to the soil-water mixture, stirring and allowing to stand for 30 minutes. The pH of the buffered soil-water mixture was read. Every 1/10 pH unit that the soil depressed the pH of the buffered solution below pH 7.0 corresponded to a lime requirement of 1,000 pounds per acre.

Phosphorus Determination. Total available phosphorus was determined according to Bray's (1) sulfonic acid reduction method. Five grams of air-dry soil was extracted with 50 ml of solution which was 0.1N HCl and 0.03N NH_4F. Each sample was shook for 60 seconds on an end-over-end shaker and filtered immediately. A 10 ml aliquot of the filtrate was placed in a colorimeter tube to which 1/2 ml of molybdate solution (P-B) and 1/2 ml of reducing reagent (P-C) were added. The percent light transmittancy was read on a Coleman Junior Spectrophotometer, at 660m , exactly 15 minutes after adding the reducing reagent (P-C).

Potassium Determination. Exchangeable (Ammonium Acetate Extractable) potassium (8) was determined using the Perkin-Elmer Flame Photometer, Model 52.

Ten grams of 10 mesh soil were placed in 125 ml erlenmeyer flasks. Fifty ml of 1N ammonium acetate solution were added. The flasks were shook for 10 minutes on an end-over-end shaker and filtered immediately. A 20 ml aliquot of each filtrate was placed in a 125 ml flask and 2 ml of a solution containing 1,100 ppm of lithium were added. Potassium was determined on the Flame Photometer using the red sensitive photocell No. 918 and a standardization solution containing 100 ppm of potassium and 100 ppm of lithium.

Base Exchange Capacity Determination. Base Exchange capacity was measured by a rapid method as adapted from Rendig (10). Two grams of air-dried, 20 mesh soil were placed in 100 ml centrifuge tubes and 25 ml of 1N potassium acetate (adjusted to pH 7.0) were added. This mixture was agitated for 30 seconds by means of a rubber ball plunger attached to an electric motor. This mixture was centrifuged at 2400 rpm for 5 minutes. This treatment was repeated 5 times in order to completely saturate the exchange complex with potassium. The soil was washed with 0.5 percent solution of potassium chloride followed by successive washings of 95 percent alcohol until the washings gave no test for chlorides. The exchangeable potassium was displaced with ammonium acetate. The solution containing the potassium was made to volume with ammonium acetate and lithium. Potassium was determined on the flame photometer using an internal standard of 100 ppm potassium and 100 ppm lithium.

Organic Matter Determination. Organic matter was determined using Carolon's modification of Graham's method (4).

One gram of 20 mesh soil was placed in a 250 ml erlenmeyer flask. Ten ml of 1N potassium dichromate were added. This was followed with 20 ml of sulphuric acid. After cooling and diluting, the suspension was filtered. The filtrate was placed in colorimeter tubes and the percent organic matter was determined using the Evelyn photoelectric colorimeter.

EXPERIMENTAL RESULTS

Chemical Analyses of Soils

The chemical analyses of the original soils are summarized in Table 3. Organic matter, pH, lime requirement, total available phosphorus, exchangeable potassium, and cation exchange capacity determinations were made on all soils prior to the growth of a crop of wheat.

Organic matter content ranged from 0.70 percent to a high of 4.32 percent. The Saline county soils were all low in organic matter except for Lancaster loam, 13-30 inches; Lancaster fine sandy loam, 10-28 inches; Niles silt loam, 0-15 inches and 15-30 inches; Lockard silt loam, 0-14 inches; and Rokeby silt loam, 0-10 inches and 10-30 inches. All of the Jackson county soils tested moderately high in organic matter ranging from 3.90 percent to 4.31 percent. So far as this worker could determine there was no correlation between content of organic matter and response to nitrogenous fertilizer.

Table 3. Soil pH values, lime requirement, organic carbon, total available phosphorus, exchangeable potassium, and cation exchange capacity for original soil samples of Saline and Jackson counties, Kansas.

Soil type	Depth of sample	pH	Pounds $CaCO_3$ required	Organic matter %	Total available P lbs/A	Exchangeable K lbs/A	Cation Exchange capacity m.e./100 gm
Berg silt loam	0-12	5.68	2000	1.74	104.0	698.5	20.70
Berg silt loam	12-28	6.25	--	0.97	76.3	451.0	30.24
Ebenezer loam	0-12	5.60	2300	1.94	87.0	583.0	17.20
Ebenezer loam	12-30	5.80	1900	1.41	51.1	414.8	23.40
Ebenezer silt loam	0-12	5.20	2500	1.93	71.5	649.0	21.45
Ebenezer silt loam	12-30	6.50	--	1.18	90.5	459.8	18.30
Edalgo silt loam	0-6	4.90	2500	1.03	20.4	275.0	9.98
Edalgo silt loam	6-20	5.60	2000	1.14	9.6	212.3	15.10
Elmo silt loam	0-11	5.70	1200	1.30	32.9	698.5	21.45
Elmo silt loam	11-30	6.15	--	0.70	24.3	438.5	26.45
Lancaster loam	0-13	5.57	2000	1.10	20.5	288.8	14.80
Lancaster loam	13-30	5.94	1800	2.52	17.7	281.6	19.05
Lancaster fine sandy loam	0-10	5.22	1800	2.02	21.0	286.0	9.30
Lancaster fine sandy loam	10-28	5.83	2200	2.50	13.5	280.5	18.30
Niles silt loam	0-15	5.40	3000	3.87	50.7	298.1	20.00
Niles silt loam	15-30	6.28	--	2.69	64.5	249.5	16.70
Lockard silt loam	0-14	5.70	2500	4.32	157.6	946.1	21.00
Lockard silt loam	14-30	6.10	--	2.17	113.0	597.7	32.10

Table 3 (concl.).

Soil type	Depth of sample	pH	Pounds $CaCO_3$ required	Organic matter %	Total available P lbs/A	Exchange-able K lbs/A	Cation exchange capacity m.e./100 gm
Rokeby silt loam	0-10	6.20	--	3.04	121.0	535.2	20.90
Rokeby silt loam	10-28	7.28	--	2.47	104.0	530.2	18.05
*Marshall, Carrington	0-12	5.86	2700	3.90	108.0	341.0	14.40
*Grundy, Pawnee, Sharpsburg	0-12	5.80	4000	4.30	20.4	237.5	17.85
*Wabash, Judson-Wabash	0-12	5.60	3000	4.31	--	333.3	18.70
*Buchard, Boone, Summit	0-12	5.70	3500	4.19	42.5	266.2	16.05

*Jackson county soils.

Hydrogen ion concentration results indicate that all soils were in the acid range except for Rokeby silt loam, 10-28 inches, which had a pH of 7.28. All of the acid soils required liming except for Berg silt loam, 12-30 inches; Ebenezer silt loam, 12-30 inches; Elmo silt loam, 11-30 inches; Lockard silt loam 14-30 inches; and Rokeby silt loam, 0-10 inches and 10-28 inches. In general, the acid Saline county soils required moderate amounts of lime to correct soil acidity while the Jackson county soils required heavier applications of lime. No lime was applied to the soils under study before growing the crop of wheat.

In general most of the soils from Saline and Jackson counties were low in total available phosphorus. According to recommendations established at Kansas State College Experiment Station (6) wheat does not require addition of phosphorus if chemical tests show 100 pounds or more total available phosphorus to be present in the soil.

All of the Jackson county soils except the Marshall, Carrington soil association group were below the minimum level of 100 pounds of total available phosphorus per acre. Of the Saline county soils all were low in total available phosphorus except Berg silt loam, 0-12 inches; Lockard silt loam, 0-14 inches and 14-30 inches; and Rokeby silt loam, 0-10 inches and 10-28 inches.

Kansas State College fertility recommendations (6) indicate that when exchangeable potassium is below 200 pounds per acre, response may be expected from applied potassium. Without exception, all of the Saline and Jackson county soils tested appreciably higher than the 200 pounds per acre of exchangeable potassium, which is estimated to be a minimum requirement.

In general the cation exchange capacity of the surface soil samples was lower than that of the subsurface soil samples. Apparently the subsurface soil samples contained a higher clay content than did the surface soil samples thus explaining the higher base exchange capacity.

Edalgo silt loam, 0-6 inches, and Lancaster fine sandy loam were found to have very low base exchange capacities. Chemical tests gave values of 9.98 m.e. per 100 gm and 9.30 m.e. per 100 gm respectively.

Analytical Results Compared with Those Obtained by Brown (3). Three soils used in this work were also studied by Brown. The three soils were: Berg silt loam, Elmo silt loam, and Lockard silt loam. The following table gives a comparative summary of the results obtained by Brown and this worker.

Table 4. A comparative summary of results obtained by Brown and Bohannon, working independently on Berg silt loam, Elmo silt loam, and Lockard silt loam.

Soil type	pH		Cation exchange cap. m.e./100 gm		Total available P lbs/acre	
	Bohannon	Brown	Bohannon	Brown	Bohannon	Brown
Lockard silt loam	5.70	6.30	21.0	20.0	157.6	18.33
Berg silt loam	5.68	5.75	20.7	20.0	104.0	13.09
Elmo silt loam	5.70	5.72	21.45	17.7	32.9	16.15

The results obtained for pH and cation exchange are in general accord, however, greatest differences show up in phosphorus results. The difference is probably due mainly to the fact that Brown used a chemical test for phosphorus as proposed by Peech, Alexander, Dean and Reed (9) while this worker used Bray's sulphonic acid method. Furthermore, Brown sampled virgin soils while the soils used in this study were all obtained from cultivated fields. Soil sampling variation plus cultural treatment differences as a result of cropping appear to be the most likely cause of variation in results.

Total Available Phosphorus Results. Total available phosphorus (2) determinations were made on all soils under treatment, within each soil type after the growth of a crop of wheat. Table 5 presents the summary of these data.

A cursory glance at the phosphorus content of the original soils shows that most of the soils under study were low in total available phosphorus. On a basis of the total available phosphorus content of the various soils, these facts become apparent:

1. Where nitrogen is applied singly, more phosphorus is taken up by the wheat plants than is taken up on the no treatment cultures.

2. Where phosphorus is applied singly there is a marked increase in total available phosphorus content of the soil. In view of the fact that monocalcium phosphate was applied at a rate of 1000 pounds per acre, it is apparent that the build-up of total available phosphorus is not additive. Apparently, phosphorus is readily fixed and reverted to less soluble forms quite

Table 5. The total available phosphorus content of Saline county soils after the growth of a crop of wheat.

Soil type	Sample depth	Total available phosphorus content, by treatment, lbs/A								
		Original soil	No treat.	N	P	K	NP	NK	PK	NPK
Berg silt loam	0-12	76.0	73.0	70.8	184.3	57.0	181.2	62.3	224.7	174.5
Berg silt loam	12-28	104.0	97.0	85.0	298.1	90.3	275.1	83.3	286.4	243.1
Ebenezer loam	0-12	87.0	60.5	66.0	233.1	57.8	233.1	52.5	284.7	219.8
Ebenezer loam	12-30	51.0	39.2	51.0	220.5	34.3	182.1	33.0	214.1	178.8
Ebenezer silt loam	0-12	71.5	54.9	49.7	218.0	64.9	207.5	46.4	223.2	186.5
Ebenezer silt loam	12-30	90.5	87.0	72.5	155.8	76.0	181.2	67.6	243.1	154.5
Edalgo silt loam	0-6	20.4	22.7	19.7	158.4	15.9	125.3	20.1	152.2	124.2
Edalgo silt loam	6-20	9.6	11.7	10.5	106.2	8.2	93.9	9.7	123.2	68.9
Elmo silt loam	0-11	32.9	31.7	28.0	168.5	26.7	157.2	27.4	195.5	152.2
Elmo silt loam	11-30	24.3	19.0	14.4	174.8	11.8	103.3	12.8	187.5	118.5
Lancaster loam	0-13	20.5	19.7	18.5	161.9	16.9	154.5	18.2	192.7	139.9
Lancaster loam	13-30	17.7	16.2	15.5	158.0	10.4	161.8	12.1	196.7	131.6
Lancaster fine sandy loam	0-10	21.0	20.0	18.5	189.8	21.8	172.2	19.3	209.8	156.5
Lancaster fine sandy loam	10-28	13.5	12.1	13.0	174.5	12.6	152.8	17.8	173.5	129.9
Niles silt loam	0-15	50.7	36.0	30.5	199.1	35.0	186.8	33.5	229.5	197.4
Niles silt loam	15-30	64.5	49.5	55.5	179.9	53.2	221.4	57.0	255.7	194.8

Table 5 (concl.).

Soil type	Sample depth	Total available phosphorus content, by treatment, lbs/A								
		Original soil	No treat.	N	P	K	NP	NK	PK	NPK
Lockard silt loam	0-14	157.6	171.3	133.0	562.0	177.7	348.5	164.6	373.0	373.0
Lockard silt loam	14-30	113.0	92.0	83.6	372.5	86.0	186.5	90.0	314.0	176.5
Rokeby silt loam	0-10	121.0	83.8	71.0	416.5	88.0	258.0	87.0	300.0	312.5
Rokeby silt loam	10-28	104.0	80.8	78.5	345.0	74.9	158.0	78.5	239.5	114.0

rapidly, depending upon the texture of the soil, organic matter content, etc.

3. Potassium applied singly, stimulated an increase in uptake of phosphorus as contrasted with no treatment tests.

4. Where nitrogen was applied in combination with phosphorus, there was increased uptake of total available phosphorus by the wheat plants. In almost every instance the total available phosphorus content on the nitrogen-phosphorus pots was lower than the total available phosphorus content of the pots where phosphorus was used singly.

5. Nitrogen and potassium applied in combination gave quite erratic results insofar as phosphorus uptake was concerned.

6. On pots where phosphorus and potassium were applied in combination, potassium did not seem to stimulate phosphorus uptake to an appreciable extent on soils originally low in phosphorus. On soils having over 100 pounds of available phosphorus per acre, potassium, apparently, contributed to increased uptake of phosphorus as contrasted with treatments where phosphorus was used alone.

7. Total available phosphorus content on treatments involving the use of nitrogen, phosphorus and potassium in combination was consistently lower than treatments involving the use of nitrogen and phosphorus, phosphorus and potassium, or phosphorus alone. Apparently, the use of nitrogen and potassium in combination with phosphorus contributed to increased uptake of phosphorus.

Exchangeable Potassium Results. Exchangeable potassium (8) determinations were run on all soil types used for the greenhouse study. After the growth of a crop of wheat, exchangeable potassium was measured on all soils involved in a set of treatments for each soil type. The results are summarized in Table 6.

A critical survey of the data presented in the above-mentioned table indicates these facts:

1. Analytical results of the original soil samples revealed that ample quantities of exchangeable potassium were present in all soils prior to the growth of a crop of wheat.

2. Uptake of potassium was appreciably increased where nitrogen was applied singly as contrasted with no treatment results.

3. Uptake of potassium where phosphorus was applied singly did not consistently contribute to the uptake of potassium to the extent that nitrogen did. Generally speaking, potassium uptake was consistently greater than on the no treatment cultures.

4. Additions of potassium consistently increased the exchangeable potassium level on all soils. Increased levels of exchangeable potassium were not additive. Appreciable quantities of the applied potassium, apparently, were tied up in less readily available forms by all soils.

5. In general, nitrogen and phosphorus applied in combination stimulated a marked increase in potassium uptake, as indicated by a reduction in the amount of exchangeable potassium present in the soil.

6. Treatments involving the use of nitrogen and potassium showed a marked increase in exchangeable potassium on surface soils

Table 6. The exchangeable potassium content of Saline county soils after the growth of a crop of wheat.

Soil type	Sample depth	Exchangeable potassium content, by treatments, lbs/A.								
		Original soil	No treat.	N	P	K	NP	NK	PK	NPK
Berg silt loam	0-12	872.3	698.5	533.5	701.8	946.0	492.8	767.8	880.0	651.7
Berg silt loam	12-28	550.0	451.0	440.0	436.2	530.8	403.7	583.0	470.3	412.5
Ebenezer loam	0-12	633.6	583.0	402.6	530.2	792.6	422.4	716.1	765.1	512.6
Ebenezer loam	12-30	673.5	414.8	393.8	391.6	555.5	369.6	557.7	641.9	388.8
Ebenezer silt loam	0-12	687.5	649.0	598.4	714.5	830.5	463.1	682.0	814.6	512.6
Ebenezer silt loam	12-30	591.8	459.8	445.5	690.9	570.4	458.2	568.7	560.5	408.1
Edalgo silt loam	0-6	318.5	275.0	280.5	194.7	473.0	198.0	492.3	410.9	232.1
Edalgo silt loam	6-20	243.1	212.3	200.2	200.2	330.0	189.2	354.8	297.0	194.7
Elmo silt loam	0-11	729.3	698.5	589.6	686.4	954.8	531.0	823.9	871.2	632.5
Elmo silt loam	11-30	554.9	438.9	418.0	445.5	568.7	413.6	585.2	598.4	418.5
Lancaster loam	0-13	322.8	288.8	236.5	276.1	510.4	253.0	451.0	504.4	298.1
Lancaster loam	13-30	177.3	281.6	269.5	280.5	413.6	253.0	473.0	443.9	280.5
Lancaster fine sandy loam	0-10	321.7	286.0	258.5	292.6	495.0	194.7	449.4	464.7	286.0
Lancaster fine sandy loam	10-28	338.8	280.5	286.0	277.2	451.0	253.0	469.2	442.2	276.1
Niles silt loam	0-15	490.6	298.1	221.8	276.8	583.6	352.6	486.8	523.6	388.8
Niles silt loam	15-30	588.5	249.5	234.5	483.5	550.0	191.1	605.0	550.0	429.5
Lockard silt loam	0-14	990.0	946.0	744.7	933.4	1226.4	722.2	715.1	1115.4	762.3
Lockard silt loam	14-30	788.7	595.7	270.5	646.8	770.0	528.0	693.0	789.8	651.7
Rokeby silt loam	0-10	603.9	535.2	423.5	546.7	731.5	429.0	530.2	719.4	488.9
Rokeby silt loam	10-28	559.4	574.2	622.1	448.3	613.8	638.0	498.3	454.0	530.2

as contrasted with treatments involving the use of potassium singly. In general, uptake of potassium from subsoil samples treated with nitrogen and potassium was found to be less marked than on the comparable subsoils where potassium was applied singly.

7. Phosphorus and potassium applied in combination gave no uniform trend insofar as potassium uptake was concerned. In general, potassium uptake was not as marked as on nitrogen-potassium treatments. However, potassium uptake was generally of greater magnitude than on treatments involving the use of potassium alone.

8. Potassium uptake on treatments involving the use of nitrogen, phosphorus and potassium in combination was consistently greater than on soil treatments involving the use of potassium alone, nitrogen and potassium, or phosphorus and potassium. Potassium uptake is apparently markedly increased where the other essential elements, nitrogen and potassium, are applied in ample amounts.

Yield Data

Pictorial Record of Growth Response. During February of 1949, a set of pictures, Plates I through XIII, was taken which appear on the following pages. They are visual evidence indicating growth response on the various soils studied under the various cultural treatments employed.

EXPLANATION OF PLATE I

A. Berg silt loam, 0-12 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Berg silt loam, 0-12 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus and potassium

PLATE I

A

B

EXPLANATION OF PLATE II

A. Berg silt loam, 12-30 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Berg silt loam, 12-30 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus and potassium

A

B

EXPLANATION OF PLATE III

A. Ebenezer loam, 0-12 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Ebenezer loam, 0-12 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus and potassium

PLATE III

A

B

EXPLANATION OF PLATE IV

A. Ebenezer loam, 12-30 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Ebenezer loam, 12-30 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus and potassium

A

B

EXPLANATION OF PLATE V

A. Ebenezer silt loam, 0-12 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Ebenezer silt loam 0-12 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus and potassium

A

B

EXPLANATION OF PLATE VI

A. Edalgo silt loam 0-6 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Edalgo silt loam, 0-6 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus and potassium

PLATE VI

A

B

EXPLANATION OF PLATE VII

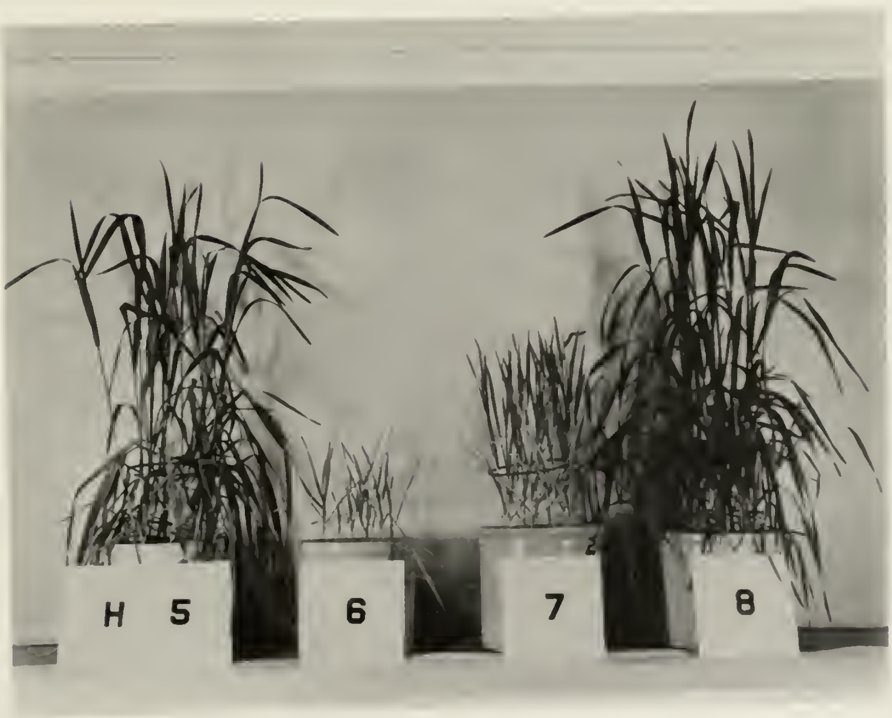
A. Idalgo silt loam, 6-20 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Idalgo silt loam, 6-20 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus, and potassium

A



B

EXPLANATION OF PLATE VIII

A. Lancaster fine sandy loam, 0-10 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Lancaster fine sandy loam, 0-10 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus and potassium

A

B

EXPLANATION OF PLATE IX

A. Lancaster fine sandy loam, 10-28 inches, showing response of wheat to fertilizer treatment

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Lancaster fine sandy loam, 10-28 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus, and potassium

A

B

EXPLANATION OF PLATE X

A. Lockard silt loam, 0-14 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Lockard silt loam, 0-14 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus, and potassium

PLATE X

A

B

EXPLANATION OF PLATE XI

A. Rokeby silt loam, 10-28 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Rokeby silt loam, 10-28 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus, and potassium

A

B

EXPLANATION OF PLATE III

A. Marshall, Carrington soil association, 0-12 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Marshall, Carrington soil association, 0-12 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus, and potassium

A

B

EXPLANATION OF PLATE XIII

A. Wabash, Judson-Wabash soil association group, 0-12 inches, showing response of wheat to fertilizer treatment:

1. No treatment
2. Nitrogen
3. Phosphorus
4. Potassium

B. Wabash, Judson-Wabash soil association group, 0-12 inches, showing response of wheat to fertilizer treatment:

5. Nitrogen and phosphorus
6. Nitrogen and potassium
7. Phosphorus and potassium
8. Nitrogen, phosphorus, and potassium

A

B

<u>Calculation of Missing Grain Yields</u>. Grain yields were obtained by weighing the actual kernels of threshed seed. However, before weighings could be completed, some of the grain samples were destroyed by mice. Inasmuch as the loss of samples was confined to a given soil or a given treatment, it was not possible to discard any portion of the data and still retain complete records for a major portion of the experiment. Therefore, it was deemed advisable to substitute values for the missing grain yields. Davis and Cook (5) have illustrated that it is possible to predict, rather accurately, the yield of grain on experimental plots by making use of the grain-straw ratio. Since all of the straw weights were obtained, a prediction of the missing grain values was accomplished in this experiment. The correlation coefficient was ascertained for the ratio between known pairs of values for grain and straw, where such complete weight data were available. The coefficient for this relationship, for all existing values without respect to treatments or soils, was found to be 0.9546. Confidence intervals were ascertained to be ± 1.215 and ± 1.600 for the .05 and .01 levels, respectively. Using the regression equation, $X = b_{xy}Y + (\bar{X} - b_{xy}\bar{Y})$, it was possible to predict the missing grain yields, where the symbols used in this equation had the following meanings:

X = estimated weight of grain

b_{xy} = regression coefficient

Y = known weight of straw

$\bar{X}$ = mean known weight of grain samples

$\bar{Y}$ = mean known weight of straw samples corresponding to $\bar{X}$

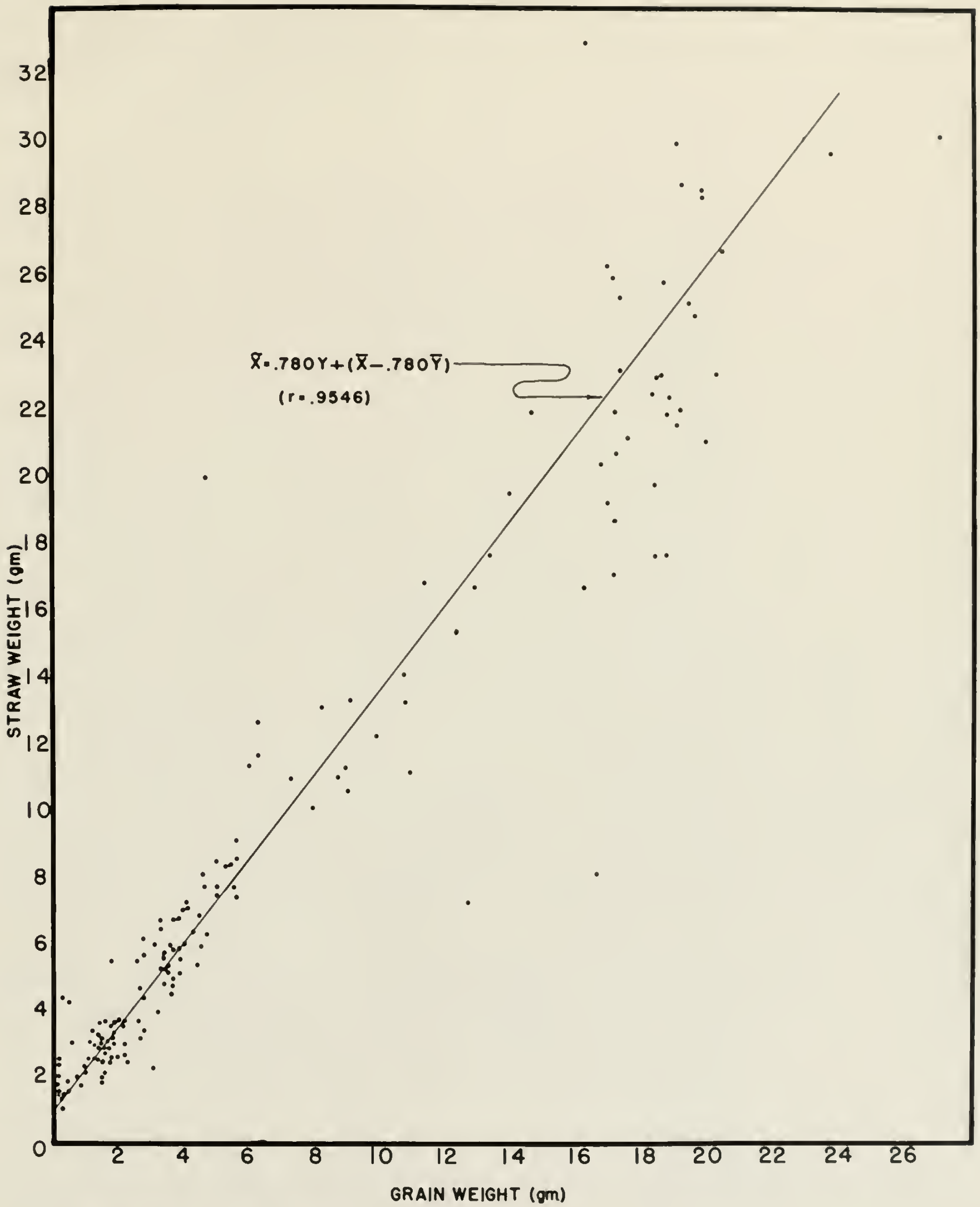


Fig I Regression of grain yields on straw yields

Table 7. Yield of grain, by treatment, for various soils used in greenhouse studies.

Soil type	Sample depth	Yield of grain, gm/pot							
		No treat.	N	P	K	NP	NK	PK	NPK
Berg silt loam	0-12	7.03	14.46	6.33	8.35	17.82	13.85	6.00	18.35
Berg silt loam	12-28	1.09	1.16	1.48	1.28	21.00	1.37	12.52	20.30
Ebenezer loam	0-12	4.70	13.30	5.82	4.42	20.01	12.23	5.35	18.62
Ebenezer loam	12-30	2.15	4.03	2.62	2.27	15.05	3.67	2.66	18.89
Ebenezer silt loam	0-12	3.35	3.47	5.18	4.39	17.11	10.71	3.61	16.78
Ebenezer silt loam	12-30	1.66	1.58	0.60	0.51	20.32	1.34	1.45	16.17
Edalgo silt loam	0-6	3.21	0.54	16.47	3.61	18.23	0.39	7.88	18.67
Edalgo silt loam	6-20	0.19	0.61	3.42	0.23	19.80	0.02	3.68	17.15
Elmo silt loam	0-11	1.37	4.99	1.80	1.83	18.36	4.61	2.02	17.21
Elmo silt loam	11-30	0.28	0.07	1.14	0.33	18.54	0.09	1.07	19.32
Lancaster loam	0-13	1.54	2.58	1.92	2.02	18.90	3.10	2.16	16.58
Lancaster loam	13-30	0.24	0.75	1.45	0.46	18.20	0.11	1.60	15.40
Lancaster fine sandy loam	0-10	1.54	1.84	1.73	1.67	16.84	3.70	2.80	16.20
Lancaster fine sandy loam	10-28	0.87	0.20	1.92	0.78	17.42	0.15	1.83	17.06
Niles silt loam	0-15	3.37	6.33	9.09	4.05	16.11	9.18	3.79	19.03
Niles silt loam	15-30	1.82	1.21	1.89	1.75	26.98	0.18	1.42	19.53
Lockard silt loam	0-14	3.35	4.72	3.33	3.14	19.44	18.45	4.12	19.71
Lockard silt loam	14-30	1.45	8.71	1.50	2.78	23.59	9.82	2.21	18.93
Rokeby silt loam	0-10	3.33	12.78	2.94	2.88	16.05	11.31	2.88	17.03
Rokeby silt loam	10-28	2.68	4.56	5.28	2.18	19.08	5.60	2.80	19.74

Table 7 (concl.).

Soil type	Sample depth	Yield of grain, gm/pot							
		No treat.	N	P	K	NP	NK	PK	NPK
Marshall, Carrington	0-12	3.51	10.77	4.13	3.74	18.22	<u>2.81</u>	4.95	<u>18.25</u>
Grundy, Sharpsburg, Pawnee	0-12	3.51	8.88	4.00	4.45	17.10	8.95	4.33	<u>12.45</u>
Wabash, Judson-Wabash	0-12	<u>5.51</u>	<u>16.55</u>	5.58	<u>13.15</u>	18.61	12.59	5.57	<u>18.40</u>
Buchard, Boone, Summit	0-12	5.51	8.15	4.99	2.76	<u>17.65</u>	10.89	2.80	<u>20.80</u>

NOTE: Underscored values represent grain samples which were destroyed by mice. These missing values were predicted according to the Regression of Grain Yield on Straw Yield graph, Fig. 1.

Table 8. Yield of straw, by treatment, for various soils used in greenhouse studies.

Soil type	Sample depth	Yield of straw, gm/pot							
		No treat.	N	P	K	NP	NK	PK	NPK
Berg silt loam	0-12	10.96	21.90	11.55	11.53	23.66	19.46	11.29	22.92
Berg silt loam	12-28	2.26	3.14	2.98	2.45	27.75	2.46	16.88	26.85
Ebenezer loam	0-12	6.25	17.56	8.30	6.80	23.10	15.35	8.32	21.68
Ebenezer loam	12-30	2.91	5.89	3.61	2.04	20.14	4.74	3.12	21.53
Ebenezer silt loam	0-12	5.16	5.20	7.48	5.34	21.89	14.05	5.87	26.22
Ebenezer silt loam	12-30	2.03	3.60	2.95	1.77	26.68	2.87	2.96	32.99
Edalgo silt loam	0-6	3.87	4.18	8.09	4.42	19.73	4.32	9.99	22.25
Edalgo silt loam	6-20	1.45	1.62	5.55	1.40	20.91	1.55	5.77	25.27
Elmo silt loam	0-11	2.76	8.41	3.53	3.18	22.96	7.63	3.62	23.13
Elmo silt loam	11-30	1.40	1.72	2.44	1.34	25.78	1.75	2.14	25.12
Lancaster loam	0-13	1.96	5.44	2.98	2.55	25.05	2.15	2.55	20.29
Lancaster loam	13-30	0.99	1.80	2.35	1.46	22.35	1.54	2.73	20.53
Lancaster fine sandy loam	0-10	1.90	5.37	2.95	2.75	18.97	4.85	3.37	17.85
Lancaster fine sandy loam	10-28	1.71	1.98	3.22	1.85	21.34	2.44	3.12	18.60
Niles silt loam	0-15	4.75	12.59	13.29	6.03	16.63	12.68	6.70	21.93
Niles silt loam	15-30	2.50	3.29	3.79	2.40	30.06	2.33	3.20	26.07
Lockard silt loam	0-14	5.55	19.85	6.71	5.92	24.65	24.45	7.20	28.30
Lockard silt loam	14-30	2.78	10.97	3.58	4.39	29.55	12.18	3.62	29.92
Rokeby silt loam	0-10	6.39	16.64	5.77	5.11	21.41	16.75	5.49	25.88
Rokeby silt loam	10-28	4.55	8.05	8.30	3.45	28.65	7.36	4.30	28.45

Table 8 (concl.).

Soil type	Sample depth	Yield of straw, gm/pot							
		No treat.	N	P	K	NP	NK	PK	NPK
Marshall, Carrington	0-12	5.23	13.15	7.06	6.66	17.56	4.44	7.40	24.27
Grundy, Sharpsburg, Pawnee	0-12	5.24	11.24	6.96	5.89	20.63	10.58	6.33	29.60
Wabash, Judson-Wabash	0-12		22.05	8.93	17.66	17.56	7.21	8.54	24.55
Buchard, Boone, Summit	0-12	7.52	13.03	7.65	5.64	23.44	11.06	6.11	27.49

Table 9. The influence of nitrogen on the yield of wheat grain.

Soil type	Sample depth	Increased yield due to nitrogen (gm)				
		N - no treat.	NP-P	NK-K	NPK-PK	Mean
Berg silt loam	0-12	7.43	11.49	5.50	12.35	9.19
Berg silt loam	12-28	0.07	19.52	0.09	7.78	6.86
Ebenezer loam	0-12	8.60	14.19	7.81	13.27	10.97
Ebenezer loam	12-30	1.88	12.43	1.40	16.23	7.99
Ebenezer silt loam	0-12	0.12	11.93	6.32	13.17	7.89
Ebenezer silt loam	12-30	-0.08	19.72	0.83	14.72	8.84
Edalgo silt loam	0-6	-2.67	1.76	-3.22	10.79	1.67
Edalgo silt loam	6-20	0.42	16.38	-0.21	13.47	7.52
Elmo silt loam	0-11	3.62	16.56	2.78	15.19	9.54
Elmo silt loam	11-30	-0.21	17.40	-0.24	18.25	8.80
Lancaster loam	0-13	1.04	16.98	1.08	14.42	8.38
Lancaster loam	13-30	0.51	16.75	-0.35	13.80	7.68
Lancaster fine sandy loam	0-10	0.30	15.11	2.03	13.40	7.71
Lancaster fine sandy loam	10-28	0.67	15.50	0.63	15.23	8.01
Niles silt loam	0-15	2.96	7.02	5.13	15.24	7.59
Niles silt loam	15-30	-0.61	25.09	-1.57	18.11	10.25
Lockard silt loam	0-14	1.37	16.11	15.31	15.59	12.09
Lockard silt loam	14-30	7.26	22.09	7.04	16.72	13.28
Rokeby silt loam	0-10	9.45	13.11	8.43	14.15	11.29
Rokeby silt loam	10-28	1.88	13.80	3.42	16.94	9.01
Marshall, Carrington	0-12	7.26	14.09	-0.93	13.30	8.43
Grundy, Pawnee, Sharpsburg	0-12	5.37	13.10	4.50	8.12	7.77
Wabash, Judson-Wabash	0-12	11.04	13.03	-0.56	12.83	9.08
Buchard, Boone, Summit	0-12	2.64	12.66	8.13	18.00	10.36

Table 10. The influence of phosphorus on the yield of wheat grain.

Soil type	Sample depth	Increased yield due to phosphorus (gm)				
		P - no treat.	NP-N	PK-K	NPK-NK	Mean
Berg silt loam	0-12	-0.70	11.49	-2.35	4.50	3.24
Berg silt loam	12-28	0.37	19.84	11.04	18.93	12.54
Ebenezer loam	0-12	1.12	14.19	0.93	6.39	5.66
Ebenezer loam	12-30	0.47	12.43	0.39	15.22	7.12
Ebenezer silt loam	0-12	1.83	11.93	-0.78	6.07	4.76
Ebenezer silt loam	12-30	-0.06	19.72	0.94	14.83	8.86
Edalgo silt loam	0-6	13.26	17.69	4.27	18.28	13.37
Edalgo silt loam	6-20	3.23	19.19	3.45	17.13	10.75
Elmo silt loam	0-11	0.43	13.37	0.19	12.60	6.64
Elmo silt loam	11-30	0.86	18.47	0.74	19.23	9.82
Lancaster loam	0-13	0.38	16.32	0.14	13.48	7.58
Lancaster loam	13-30	1.21	17.45	1.14	15.29	8.77
Lancaster fine sandy loam	0-10	0.19	15.00	1.03	12.50	7.18
Lancaster fine sandy loam	10-28	0.05	17.22	1.05	16.91	8.81
Niles silt loam	0-15	5.72	9.78	-0.26	9.85	6.27
Niles silt loam	15-30	0.07	25.77	-0.33	19.35	11.21
Lockard silt loam	0-14	0.02	14.72	0.98	1.26	4.23
Lockard silt loam	14-30	0.05	14.88	0.57	9.11	6.15
Rokeby silt loam	0-10	-0.39	3.27	0.00	5.72	2.17
Rokeby silt loam	10-28	2.60	14.52	0.62	14.14	7.97
Marshall, Carrington	0-12	0.62	7.45	1.21	15.44	6.18
Grundy, Pawnee, Sharpsburg	0-12	0.49	13.10	-0.21	3.50	4.22
Wabash, Judson-Wabash	0-12	0.07	2.05	-7.58	5.81	0.11
Buchard, Boone, Summit	0-12	-0.52	9.50	0.04	9.91	4.73

Table 11. The influence of potassium on the yield of wheat grain.

Soil type	Sample depth	Increased yield due to potassium (gm) K - no treat.	NK-N	PK-P	NPK-NP	Mean
Berg silt loam	0-12	1.32	-0.61	-0.33	0.53	0.23
Berg silt loam	12-30	0.19	0.21	1.04	-0.70	0.19
Ebenezer loam	0-12	0.28	-1.07	-0.47	-1.39	-0.66
Ebenezer loam	12-30	0.12	-0.36	0.04	3.84	0.91
Ebenezer silt loam	0-12	1.04	7.24	-1.57	-0.33	1.59
Ebenezer silt loam	12-30	-1.15	-0.24	0.94	4.15	0.93
Edalgo silt loam	0-6	0.40	-0.15	-8.59	0.44	-1.97
Edalgo silt loam	6-20	-0.04	-0.59	-0.26	-2.65	-0.89
Elmo silt loam	0-11	0.46	-0.38	0.22	-1.15	-0.21
Elmo silt loam	11-30	0.05	0.02	-0.07	0.78	0.20
Lancaster loam	0-13	0.48	0.52	0.24	-2.32	0.27
Lancaster loam	13-30	0.22	-0.64	0.15	-2.80	-0.77
Lancaster fine sandy loam	0-10	0.13	1.86	1.07	-0.64	0.61
Lancaster fine sandy loam	10-28	-0.09	-0.05	-0.09	-0.36	-0.15
Niles silt loam	0-15	0.68	2.85	-5.30	2.92	0.29
Niles silt loam	15-30	-0.07	-1.03	-0.47	-7.45	-2.25
Lockard silt loam	0-14	-0.21	13.73	0.79	0.27	3.64
Lockard silt loam	14-30	1.33	1.11	0.71	-4.66	-0.38
Rokeby silt loam	0-10	-0.45	-1.47	-0.06	0.98	-0.25
Rokeby silt loam	10-28	-0.50	1.40	-2.48	0.66	-0.23
Marshall, Carrington	0-12	0.23	-7.96	0.82	0.03	-1.72
Grundy, Pawnee, Sharpsburg	0-12	0.94	0.07	0.33	-4.65	-0.83
Wabash, Judson-Wabash	0-12	7.64	-3.96	-0.01	-0.21	0.86
Buchard, Boone, Summit	0-12	-2.75	2.74	-2.19	3.15	0.24

Table 12. The influence of nitrogen on the yield of wheat straw.

Soil type	Sample depth	Increased yield due to nitrogen (gm)				
		N - no treat.	NP-P	NK-K	NPK-PK	Mean
Berg silt loam	0-12	10.94	12.11	7.93	11.63	10.65
Berg silt loam	12-30	0.88	14.77	1.01	9.97	6.66
Ebenezer loam	0-12	11.31	14.80	8.55	13.36	12.01
Ebenezer loam	12-30	2.98	16.53	2.70	18.41	10.16
Ebenezer silt loam	0-12	0.04	14.41	8.71	20.35	10.88
Ebenezer silt loam	12-30	1.57	23.73	1.10	30.03	14.11
Edalgo silt loam	0-6	0.31	11.64	-0.10	12.26	6.03
Edalgo silt loam	6-20	0.17	15.36	0.15	19.50	8.80
Elmo silt loam	0-11	5.65	19.43	4.45	19.51	12.26
Elmo silt loam	11-30	0.22	23.34	0.41	22.98	11.74
Lancaster loam	0-13	3.48	22.07	-0.40	17.74	10.72
Lancaster loam	13-30	0.81	20.05	0.08	17.80	9.69
Lancaster fine sandy loam	0-12	3.47	16.02	2.10	14.48	9.02
Lancaster fine sandy loam	12-28	0.27	18.12	0.59	15.48	8.61
Niles silt loam	0-15	7.84	3.34	6.65	15.23	8.27
Niles silt loam	15-30	0.79	26.27	-0.07	22.87	12.50
Lockard silt loam	0-14	14.30	17.94	18.53	21.10	17.97
Lockard silt loam	14-30	8.19	25.97	7.79	26.30	17.06
Rokeby silt loam	0-10	10.25	15.64	11.64	20.39	14.48
Rokeby silt loam	10-28	3.50	20.35	3.91	24.15	12.98
Marshall, Carrington	0-12	7.92	10.50	-2.22	16.87	8.27
Grundy, Pawnee, Sharpsburg	0-12	6.00	13.67	4.69	23.27	11.91
Wabash, Judson-Wabash	0-12	--	8.63	-10.45	16.01	3.55
Buchard, Boone, Summit	0-12	5.55	15.79	5.42	21.38	12.03

Table 13. The influence of phosphorus on the yield of wheat straw.

Soil type	Sample depth	Increased yield due to phosphorus (gm)				
		P - no treat.	NP-N	PK-K	NPK-NK	Mean
Berg silt loam	0-12	0.59	1.76	-0.24	2.46	1.14
Berg silt loam	12-30	0.02	24.61	14.43	24.39	16.86
Ebenezer loam	0-12	2.05	5.54	1.52	6.33	3.86
Ebenezer loam	12-30	0.70	14.25	0.88	16.79	8.16
Ebenezer silt loam	0-12	2.32	16.69	0.53	12.17	7.93
Ebenezer silt loam	12-30	0.92	23.08	1.19	30.12	13.83
Hidalgo silt loam	0-6	4.22	15.55	5.57	17.93	10.82
Hidalgo silt loam	6-20	4.10	19.29	4.37	23.72	12.87
Elmo silt loam	0-11	0.77	14.55	0.44	15.55	7.83
Elmo silt loam	11-30	1.04	24.06	0.80	23.37	12.32
Lancaster loam	0-13	1.02	19.61	0.00	18.14	9.69
Lancaster loam	13-30	1.36	20.55	1.27	18.99	10.54
Lancaster fine sandy loam	0-12	1.05	13.60	0.62	13.00	7.07
Lancaster fine sandy loam	12-28	1.51	0.36	1.27	16.16	4.82
Niles silt loam	0-15	8.54	4.04	0.67	9.25	5.63
Niles silt loam	15-30	1.29	26.77	0.80	23.74	13.15
Lockard silt loam	0-14	1.16	4.80	1.28	3.85	2.77
Lockard silt loam	14-30	0.80	18.58	-0.77	17.74	9.09
Rokeby silt loam	0-10	-0.62	4.77	0.38	9.13	4.41
Rokeby silt loam	10-28	3.75	20.60	0.95	21.09	11.60
Marshall, Carrington	0-12	1.83	4.41	0.74	19.83	6.70
Grundy, Pawnee, Sharpsburg	0-12	1.72	9.39	0.44	19.02	7.64
Wabash, Judson-Wabash	0-12	--	-4.49	-9.12	17.34	0.93
Buchard, Boone, Summit	0-12	0.13	20.41	0.47	16.43	9.36

Table 14. The influence of potassium on the yield of wheat straw.

Soil type	Sample depth	Increase in yield due to potassium (%)				
		K - no treat.	NK-N	PK-P	NPK-NP	Mean
Berg silt loam	0-12	0.57	-1.44	-0.26	-0.74	-0.47
Berg silt loam	12-30	0.19	-0.68	13.90	-0.90	3.12
Ebenezer loam	0-12	-0.55	-2.21	0.02	-1.42	-1.06
Ebenezer loam	12-30	-0.87	-1.15	-0.49	1.39	-0.28
Ebenezer silt loam	0-12	0.18	8.85	1.61	4.33	3.74
Ebenezer silt loam	12-30	-0.26	-0.73	0.01	6.31	1.34
Edalgo silt loam	0-6	0.55	0.14	1.90	2.52	1.28
Edalgo silt loam	6-20	-0.05	-0.10	0.22	4.36	1.11
Elmo silt loam	0-11	0.42	-0.78	0.09	1.17	0.23
Elmo silt loam	11-30	-0.38	0.03	-0.30	-0.66	-0.33
Lancaster loam	0-13	0.59	-3.29	-0.43	-4.76	-1.97
Lancaster loam	13-30	0.47	-0.26	0.38	-1.82	0.31
Lancaster fine sandy loam	0-12	0.85	-0.52	0.42	-1.12	-0.09
Lancaster fine sandy loam	12-28	0.14	0.46	-0.10	2.74	0.81
Niles silt loam	0-15	1.28	0.08	-6.59	5.30	0.02
Niles silt loam	15-30	-0.10	-0.96	-0.59	-4.99	-1.66
Lockard silt loam	0-14	0.37	4.60	0.49	3.65	2.28
Lockard silt loam	14-30	1.61	1.21	0.04	4.37	1.81
Rokeby silt loam	0-10	-1.28	0.11	0.28	4.47	0.89
Rokeby silt loam	10-28	-1.10	0.69	-4.00	-0.20	-1.15
Marshall, Carrington	0-12	1.43	-8.71	0.34	6.71	-0.06
Grundy, Pawnee, Sharpsburg	0-12	0.65	-0.66	-0.63	8.97	2.08
Wabash, Judson-Wabash	0-12	--	-14.84	-0.39	6.99	-2.74
Buchard, Boone, Summit	0-12	-1.88	-1.97	-1.54	4.05	-0.33

The validity of using such procedure to calculate the missing grain values seemingly is reasonably well established when consideration is given the confidence limits. It is, of course, apparent that considerable error is involved in predicting the small-sized missing yield values because in such instances the yield of grain, as calculated by the correlation coefficient, was in several cases less than the magnitude of the confidence interval. However, most of the missing values were large in size, so it may be assumed that a reasonably accurate prediction has been accomplished.

Missing grain yields are indicated in Table 7 by being underscored. The regression, $\tilde{X} = b_{xy}Y + (\bar{X} - b_{xy}\bar{Y})$, is plotted in Fig. 1.

Evaluation of the Effect of Various Fertilizer Treatments. In order to evaluate the response of wheat on the various cultures to each of the fertilizer elements, four comparisons were made with respect to each element. The following comparisons were made to evaluate response to nitrogen:

1. Nitrogen minus no treatment
2. Nitrogen-phosphorus minus phosphorus
3. Nitrogen-potassium minus potassium
4. Nitrogen-phosphorus-potassium minus phosphorus-potassium

The following comparisons were made to evaluate response to phosphorus:

1. Phosphorus minus no treatment
2. Nitrogen-phosphorus minus nitrogen
3. Phosphorus-potassium minus potassium

4. Nitrogen, phosphorus-potassium minus nitrogen-potassium

The following comparisons were made to evaluate response to potassium:

1. Potassium minus no treatment
2. Nitrogen-potassium minus nitrogen
3. Phosphorus-potassium minus phosphorus
4. Nitrogen-phosphorus-potassium minus nitrogen-phosphorus

Summaries of the above comparisons to indicate the influence of the various fertilizer elements on grain yields are shown in Tables 9, 10 and 11. Similar summaries for the influence of the various fertilizer elements on straw yields are shown in Tables 12, 13 and 14.

In general on all soils, very marked increases in the yield of grain resulted whenever nitrogen was used in combination with phosphorus or in combination with phosphorus and potassium. In some instances the use of nitrogen alone and in combination with potassium also gave sizable yield increases. Such increases were noted for the Berg silt loam, 0-12 inches; for the Ebenezer loam, 0-12 inches; for the Niles silt loam, 0-15 inches; for the Lockard silt loam, 0-14 inches and 14-30 inches; and for the Rokeby silt loam, 0-10 inches. Smaller increases of this same nature were noted for the Ebenezer loam, 12-30 inches; for the Elmo silt loam, 0-11 inches; for the Lancaster loam, 0-13 inches; for the soil of the Grundy-Pawnee-Sharpsburg association and for the soil of the Buchard-Boone-Summit association. In some instances there was an apparent response to nitrogen either when this element was used alone or when used in combination with potassium. However, these instances were few and appeared to be erratic. Therefore, it logically may be concluded that the soils may be divided into two groups. The first group includes those enumerated above where response to nitrogen was noted in all instances where the treatment included nitrogen, irrespective of what other elements might have been in combination with it. The other group of soils can be considered as responsive to nitrogen only when phosphorus is used in combination with this element. All soils not specifically enumerated above apparently fall into this category.

In general on all soils, very marked increases in grain yield resulted whenever phosphorus was used in combination with nitrogen or in combination with nitrogen and potassium. In some instances, phosphorus used alone and in combination with potassium gave a material response. Where phosphorus was used alone, marked increases were noted on Edalgo silt loam, 0-6 inches, while a moderate response was noted on the Edalgo silt loam, 6-20 inches, and Niles silt loam 0-15 inches. Weak response to phosphorus alone was noted on Ebenezer loam, 0-12 inches; Ebenezer silt loam, 0-12 inches; and Lancaster loam 13-30 inches. Where phosphorus was used in combination with potassium, a marked increase in yield was noted on Berg silt loam, 12-30 inches. Moderate to weak increases due to phosphorus, when used in combination with potassium, were observed on Edalgo silt loam, 0-6 and 6-20 inches; Lancaster loam 13-30 inches; and the Marshall-Carrington soil association group.

Except for the few above-mentioned instances, it is clear that on all soil types studied the greatest response to phosphorus is achieved only when it is used in combination with nitrogen or nitrogen and potassium. Inasmuch as potassium has not been found to materially increase grain yields, it is doubtful whether it contributes to phosphorus response.

In general, potassium was found to give no consistent marked increase in yield, when used alone or in combination with other elements. There were several exceptions in that potassium applied in combination with nitrogen gave a marked response on Lockard silt loam, 0-14 inches; Ebenezer silt loam, 0-12 inches; and Wabash, Judson-Wabash soil association group. The Buchard-Boone-Summit soil association group gave a weak response to potassium when applied in combination with phosphorus, and nitrogen and phosphorus.

Except for isolated instances, the evidence indicates that potassium fertilization did not consistently and materially increase grain yields.

The Relationship of Wheat Yield Response to Available Plant Nutrients as Measured by Chemical Means

It was readily apparent that the various soils used in the experiment were responsive especially to added nitrogen and phosphorus. There was considerable evidence to indicate that certain of these soils were deficient in phosphorus and much evidence to indicate a lack of organic matter upon the basis of chemical analyses. In general, no deficiency of exchangeable potassium was indicated. However, inasmuch as the ultimate practical value of any chemical method for assaying soil fertility depends upon the suitability of that method for predicting plant growth response from the addition of a given nutrient, it was decided to attempt to evaluate the relationships between these factors. The principles outlined by Bray (2) and Smith (12) were used in these evaluations. In the case of each of these fertilizer elements, percentage yields were calculated by comparing the yield on the culture where one element was omitted from the treatment, but where the other two were included, with the yield on the culture where the element under consideration was added in the presence of the other two. Thus, in order to evaluate nitrogen response the yields from the phosphorus-potassium cultures were compared with the nitrogen-phosphorus-potassium cultures; in order to evaluate phosphorus response the yields from the nitrogen-potassium cultures were compared with the nitrogen-phosphorus-potassium cultures; and in order to evaluate potassium response the yields from the nitrogen-phosphorus cultures were compared with the nitrogen-phosphorus-potassium cultures.

The relationship between organic matter content and response to added nitrogen is shown in Fig. 2. Apparently there is no definite relationship between response to added nitrogen and organic matter content. There are no indications that the subsoil materials, which in general were somewhat lower in organic matter content than the surface soils, were any more responsive to added nitrogen than the surface soils. As a matter of fact, the Berg silt loam subsoil with an organic matter content of only 0.97 percent was the least responsive to added nitrogen.

It is not easy to explain why there was not somewhat greater relationship between these two factors. However, two points need be considered. First of all, most of the soil materials were very low in organic matter content. For this reason it may be assumed that there was not an adequate distribution of samples so as to represent soils which were high in organic matter content. Secondly, all of the soils were very responsive to added nitrogen. Perhaps these soils were more responsive to added nitrogen than is normal for wheat producing soils or perhaps the growth of wheat under greenhouse conditions permitted somewhat more response than usual. Thus, an exaggeration of response might have been indicated. Nevertheless, it is apparent from Fig. 2 that there is a definite lack of relationship between these two factors, so it must be concluded from the results of this experiment that chemically measured organic matter content of the soil is not a good measure of the ability of the soil to supply nitrogen for the growth of wheat.

The relationships between total available phosphorus content and response to added phosphorus are shown in Fig. 3. Examination of the plot of points indicates that the various soil materials do not behave similarly. The surface soil samples from Saline county seem to lie rather close to the curve plotted for these samples according to the equation:

$$\log (A - Y) = \log A - c_1 b_1$$

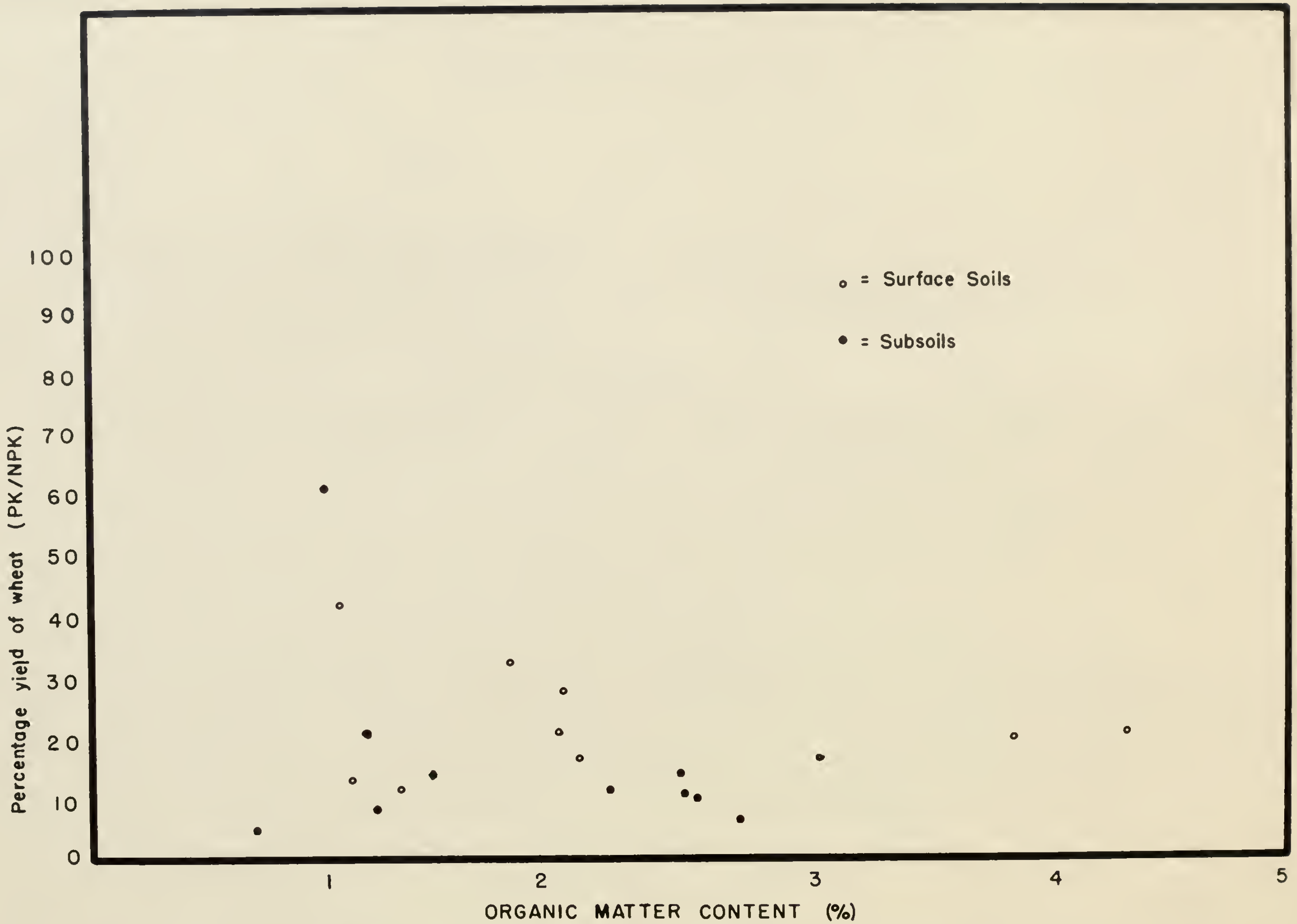


Fig. 2. Relationships between organic matter content and response to added nitrogen, Saline county soils

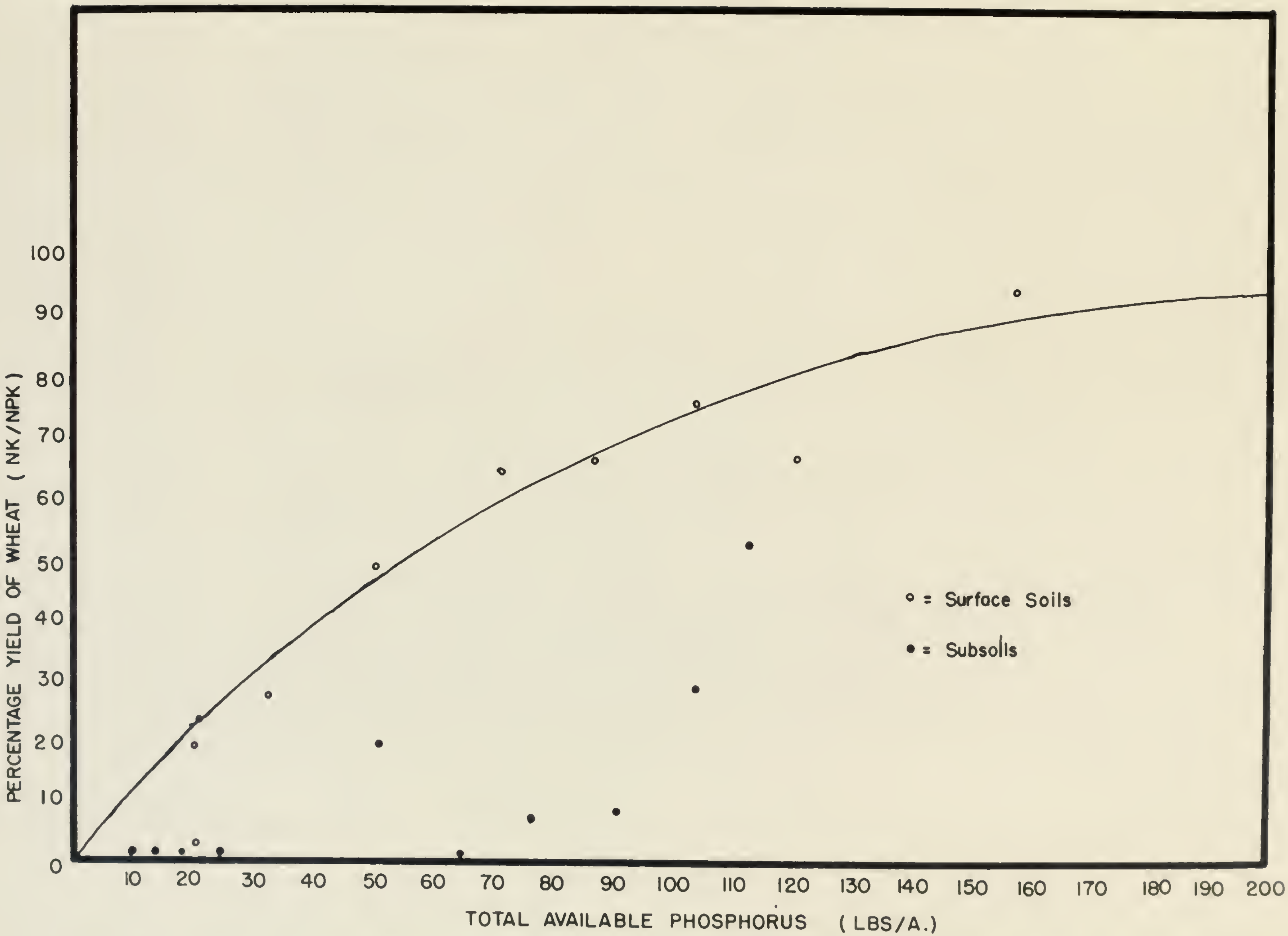


Fig. 3. Relationship between total available phosphorus and response to added phosphorus, Saline county soils

where A = yield when phosphorus is not deficient (NPK), Y = yield when no phosphorus is added (NK), b_1 = soil test value for total available phosphorus and c_1 = the proportionality constant. Inasmuch as all values were known except those of c_1, it was possible to calculate these. Using the mean of the c_1 values, it was possible to plot the curve indicated in Fig. 3. A statistical analysis of the various c_1 values is given in Table 15.

Table 15. Statistical analysis of c_1 values for the various soils of Saline county.

Statistic	Value of statistic
$\bar{x}$	.005300
σ	.001031
V	19.50
$\sigma_{\bar{x}}$ (actual)	$\pm$.00326
$\sigma_{\bar{x}}$ (percent)	$\pm$6.15

Calculation of the standard error of estimate gave a value of $\pm$6.15. This indicates that the chemical measurement of available phosphorus in the surface soils of Saline county provided a satisfactory means of predicting probable phosphorus response. A standard error of estimate of $\pm$6.15 percent compares favorably with a similar value of $\pm$4.11 percent obtained by Smith (12) for a larger number of samples involved in a phosphorus study in Michigan and a standard error of estimate of $\pm$5.0 percent reported by Bray (2) for his potassium studies on a somewhat larger sample of Illinois soils. It is obvious that the subsoil samples from Saline county do not fall close enough to the curve to be regarded in the same category. Likewise, there apparently was no similar close curvilinear relationships between available phosphorus and percentage yield in the subsoil materials as was true for the surface samples.

Apparently, the phosphorus contained in the subsoil materials of Saline county was relatively much less available than that present in the surface soils. This fact is suggested by the distribution of points in Fig. 3 representing the subsoil materials, because every one of these points falls well below the corresponding surface sample. Inasmuch as the subsoil materials gave a much greater percentage response than the surface sample, it must be concluded that there was a much lower degree of availability of phosphorus in the subsoil than in the surface. With the exception of a very few samples, it appeared that the subsoil materials of the Saline county soils were not capable of furnishing very much phosphorus for the growth of wheat. It might be postulated that badly eroded soils of this area would be especially responsive to phosphorus. Likewise any chemical test to measure available phosphorus apparently would be much less valuable in these instances than it would be when used on normal surface soil materials because of the exposure of subsoil materials with relatively unavailable forms of phosphorus.

The relationship between exchangeable potassium content and response to added potassium is shown in Fig. 4. Two facts are immediately apparent. First, it is obvious that there was no great response to added potassium such as was true for phosphorus and nitrogen where every soil material gave marked response. More than half of all the samples actually gave decreases in yields as a result of added potash. Most of these decreases were relatively slight and may be disregarded. However, some apparently were large enough to be a factor of importance. Secondly, there was a distinct lack of relationship between exchangeable potassium content and response to added potassium. Part of this lack of relationship between these two factors is undoubtedly due to the fact that, in general, the soils all possessed large amounts of exchangeable potassium and for that reason a fair sample was not provided. Apparently wheat is much less responsive to added potassium than to added nitrogen or phosphorus.

It may be concluded that, in general, potassium need not be added to soils of this type and inasmuch as this is true, it is not an important fact that there is no definite relationship between exchangeable potassium content and response of wheat to added potash.

DISCUSSION

General Observations for Each Soil Type

Berg Silt Loam. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen-phosphorus, and

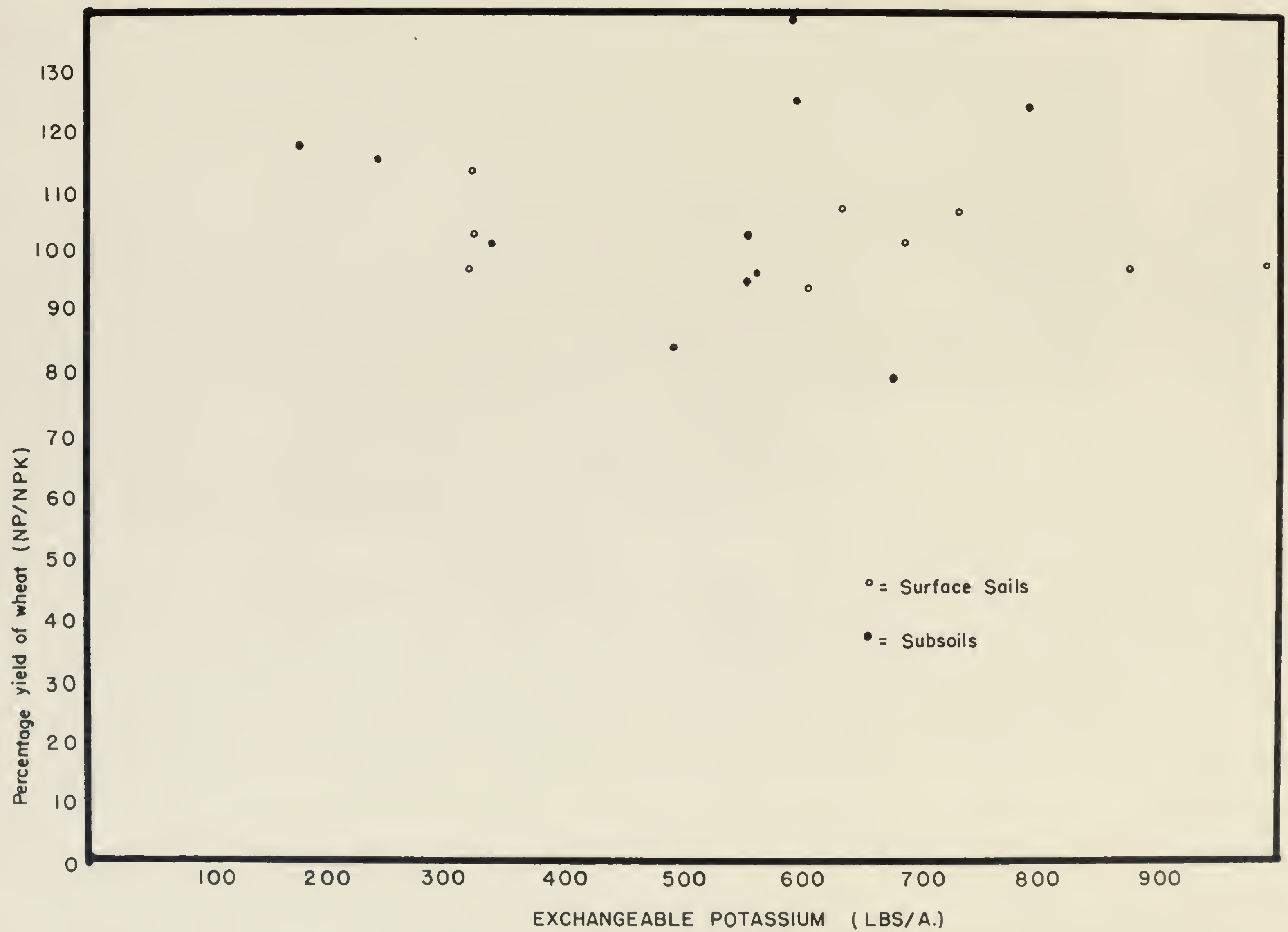


Fig. 4. Relationship between exchangeable potassium and response to added potassium, Saline county soils

nitrogen-phosphorus-potassium treatments gave the greatest growth response.

Yield data showed that grain and straw yields were materially increased on the nitrogen-phosphorus and the nitrogen-phosphorus-potassium treatments. The surface soil showed a marked response to nitrogen, but a lesser response to phosphorus. Berg silt loam surface soil apparently possesses a comparatively large amount of available phosphorus. Potassium was found to give no material response of any treatment.

Greenhouse results indicate that yields on the Berg soils were significantly increased by the application of nitrogen and phosphorus. The most marked increases were obtained through the use of nitrogen and phosphorus in combination.

Ebenezer Loam. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen-phosphorus and nitrogen-phosphorus-potassium treatments gave the greatest growth response.

Yield results indicated that nitrogen applied singly and in combination to the surface soil increased the yield of straw and grain. Most phosphorus response was noted when this element was used in combination with nitrogen. Potassium did not give an increase in grain or straw yields.

Greenhouse results indicate that this soil will respond to applications of nitrogen and phosphorus, but will give no significant yield increase from potassium. The yield data indicate that response was obtained from nitrogen when used alone; however, the use of nitrogen and phosphorus in combination gave the greatest yield increase.

Ebenezer Silt Loam. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen-phosphorus and nitrogen-phosphorus-potassium treatments gave the greatest yields of grain.

Yield results showed the surface and subsoil gave yield increases from applications of combinations of fertilizer materials which included both nitrogen and phosphorus. The subsoil gave a more marked yield increase than did the surface soil, based on the mean yield data. A response to potassium was noted on the surface soil when this element was used in combination with nitrogen, but it is questionable whether it was significant since other combinations in which potassium was evaluated did not behave similarly.

Greenhouse results indicate that this soil will respond to applications of fertilizers supplying both nitrogen and phosphorus. It will give but slight or no response to potassium.

Edalgo Silt Loam. Greenhouse observations during the growth period of the wheat crop indicated phosphorus used alone, nitrogen-phosphorus, and nitrogen-phosphorus-potassium treatments gave the most marked growth response. Apparently, most of this response was due to phosphorus in the case of the surface soil.

Yield results showed that nitrogen and phosphorus gave yield increases on both surface and subsoil. The surface soil gave a greater response to phosphorus, while the subsoil responded most to nitrogen. Potassium gave no yield response.

Greenhouse yield results indicated that Hidalgo silt loam will respond to applications of phosphorus, used singly or in combination with nitrogen.

Elmo Silt Loam. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen-phosphorus and nitrogen-phosphorus-potassium treatments gave the greatest yield response.

Yield results indicated that the straw and grain yields were increased on the nitrogen, nitrogen-phosphorus, and nitrogen-phosphorus-potassium treatments. Yield data indicate that Elmo silt loam gave the greatest response to nitrogen while the subsoil responded most to phosphorus. Potassium did not give increases for straw or grain yields.

Greenhouse results indicate that yields on the Elmo silt loam were significantly increased from the use of nitrogen, used singly or in combination with phosphorus, and from the use of phosphorus when this element was supplied in combination with nitrogen.

Lancaster Loam. Greenhouse observations during the growth period of the wheat crop indicated that the nitrogen-phosphorus, and nitrogen-phosphorus-potassium treatments gave the best results.

Yield data showed that grain and straw yields were increased on the nitrogen-phosphorus and nitrogen-phosphorus-potassium treatments. There was no appreciable difference between the surface soil and subsoil regarding response to nitrogen and phosphorus. The surface soil and the subsoil gave no response to potassium.

Greenhouse results indicated that yields on the Lancaster loam were significantly increased by the application of nitrogen and phosphorus in combination. Potassium was, apparently, of no benefit.

Lancaster Fine Sandy Loam. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen-phosphorus and nitrogen-phosphorus-potassium treatments gave the greatest growth response.

Yield data showed that grain and straw yields were significantly increased on the nitrogen-phosphorus and the nitrogen-phosphorus-potassium treatments. Potassium, however, was found to give no response when this element was evaluated individually. The Lancaster subsoil showed somewhat more response to nitrogen and phosphorus than did the surface soil.

Greenhouse results indicated that yields on the Lancaster fine sandy loam were increased by fertilizer treatment. The most pronounced yield increases resulted from the use of nitrogen and phosphorus in combination. Less marked response resulted when nitrogen and phosphorus were used singly. Apparently, no response can be attributed to potassium, especially on the subsoil.

Niles Silt Loam. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen and phosphorus gave a response whether used alone or in combination with other elements in the case of the surface soil.

Yield data showed that grain and straw yields were significantly increased where nitrogen and phosphorus had been used. The surface soil responded well to nitrogen and phosphorus, but the subsoil showed a much greater response to combinations of nitrogen and phosphorus. Neither surface nor subsoil showed a large increase due to potassium.

Greenhouse results indicate that yields on the Niles silt loam were significantly increased by fertilizer treatment. The most pronounced increases resulted from the use of nitrogen and phosphorus in combination. Less marked response resulted when nitrogen and phosphorus were used singly.

Lockard Silt Loam. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen applications gave very definite response. There was some slight evidence of phosphorus response.

Yield data showed that grain and straw yields were significantly increased by nitrogen and phosphorus applications. Nitrogen, apparently, was responsible for the greatest part of the response attributable to the combination of nitrogen and phosphorus. Potassium was found to give no response on the subsoil, but gave a response on the surface soil when used in combination with nitrogen.

Greenhouse results indicate that yields on the Lockard soils were increased by the applications of nitrogen and phosphorus fertilizers. It is questionable whether potassium would consistently give a yield response. The most marked responses were obtained through the use of nitrogen and phosphorus in combination.

<u>Rokeby Silt Loam</u>. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen and phosphorus applications gave the greatest growth response.

Yield data showed that grain and straw yields were increased by nitrogen and phosphorus applications. Yield increases on both the surface soil and subsoil were due primarily to nitrogen. Potassium gave no response on either surface soil or subsoil.

Greenhouse results indicated that yields on the Rokeby soils were increased by the application of nitrogen and phosphorus. Nitrogen and phosphorus applied in combination gave the greatest yield response; but, nitrogen used alone was very effective in increasing yields on this soil type, especially in the surface layer.

<u>Marshall-Carrington</u>. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen applications were giving growth response. Visible response to phosphorus were not too evident. Potassium applications gave no apparent response.

Yield data showed that grain and straw yields were significantly increased by applications of nitrogen and phosphorus. Potassium did not increase yields. Nitrogen gave the most marked yield response, while phosphorus response was slightly less marked.

Greenhouse results indicated that this soil association group gave greatest yield increases from the application of nitrogen and phosphorus in combination. Potassium is not likely to give a yield response.

Grundy, Sharpsburg, and Pawnee. Greenhouse observations during the growth period of the wheat crop indicated that applications of nitrogen and phosphorus, applied together, gave response. It was, also, apparent that nitrogen, used alone, gave a growth response.

Yield data showed that grain and straw yields were increased by applications of nitrogen and phosphorus in combination. Yield data indicated that the greater portion of the yield response was due to nitrogen with a lesser amount attributed to phosphorus.

Greenhouse results indicated that this soil association group gave a significant yield increase from the use of nitrogen and phosphorus fertilizers in combination. Potassium is not likely to give consistent yield increases.

Wabash, Judson-Wabash. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen and phosphorus gave a yield response. Nitrogen used alone appeared to give marked response.

Yield results showed that grain and straw yields were increased by the use of nitrogen and phosphorus applied in combination. Potassium gave no response for straw yields, but did show a response when used alone. However, this effect was absent when potassium was used in combination with other elements.

Greenhouse results indicated that this soil association gave a marked response to nitrogen, with a lesser degree of response due to phosphorus. Potassium may give a grain yield response.

Buchard, Boone, Summit. Greenhouse observations during the growth period of the wheat crop indicated that nitrogen gave a marked yield response. Phosphorus appeared to be giving a somewhat less response while potassium showed little response.

Yield data showed that grain and straw yields were increased by the use of nitrogen and phosphorus in combination. Potassium gave no response.

Greenhouse results indicated that this soil association gave marked response to nitrogen and phosphorus applied in combination.

Catena Relationships

The chemical test results of all soils, by catenas, from Saline county, Kansas, are summarized in Table 16.

The pH of all surface soils was weak to moderately acid. Generally speaking, the pH values of the subsoils indicated they were less acid than the surface soils. In general, the subsoils from the Edalgo and Lancaster catenas were quite acid as contrasted with the soils of the Berg, Ebenezer, Niles catena; the Lockard, Rokeby catena; and the Elmo catena.

Organic matter determinations indicate these facts:

1. Soils of the Lockard-Rokeby catena were relatively high in organic matter.

2. Soils of the Berg, Ebenezer, Niles catena and the Lancaster catena were medium to low in organic matter.

3. Soils of the Elmo catena and the Edalgo catena were low in organic matter.

Table 16. Summary of chemical analyses of soils from Saline county, by catenas.

Catena	Sample depth	pH	Percent organic matter	Lbs. total available P per acre	Lbs. of exchangeable K per acre	Cation exch. capacity m.e. per 100 gm
Berg, Ebenezer, Niles Catena						
Berg silt loam	0-12	5.68	1.74	104.0	698.5	20.70
Berg silt loam	12-30	6.25	0.97	76.3	451.0	30.24
Ebenezer silt loam	0-12	5.20	1.93	71.5	649.0	21.45
Ebenezer silt loam	12-30	6.50	1.18	90.5	459.8	18.30
Ebenezer loam	0-12	5.60	1.94	87.0	583.0	17.20
Ebenezer loam	12-30	5.80	1.41	51.1	414.8	23.40
Niles silt loam	0-12	5.40	3.87	50.7	298.1	20.00
Niles silt loam	12-30	6.28	2.69	64.5	249.5	16.70
Lockard, Rokeby Catena						
Lockard silt loam	0-14	5.70	4.32	157.6	946.1	21.00
Lockard silt loam	14-30	6.10	2.17	113.0	597.7	32.10
Rokeby silt loam	0-10	6.20	3.04	121.0	535.2	20.90
Rokeby silt loam	10-28	7.28	2.47	104.0	530.2	18.05
Edalgo Catena						
Edalgo silt loam	0-6	4.90	1.03	20.4	275.0	9.98
Edalgo silt loam	6-20	5.60	1.14	9.6	212.3	15.10
Lancaster Catena						
Lancaster loam	0-13	5.57	1.10	20.5	288.8	14.80
Lancaster loam	13-30	5.94	2.52	17.7	281.6	19.05

Table 16 (concl.).

Catena	Sample depth	pH	Percent organic matter	Lbs. total available P per acre	Lbs. of exchangeable K per acre	Cation exch. capacity m.e. per 100 gm
Lancaster Catena (concl.)						
Lancaster fine sandy loam	0-10	5.22	2.02	21.0	286.0	9.30
Lancaster fine sandy loam	10-28	5.83	2.50	13.5	280.5	18.30
Elmo Catena						
Elmo silt loam	0-11	5.70	1.30	32.9	698.5	21.45
Elmo silt loam	11-30	6.15	0.70	24.3	438.5	26.45

Chemical analysis results indicated that soils of the Lockard, Rokeby catena are comparatively high in total available phosphorus, while soils of the Berg, Ebenezer, Niles catena are medium to low in total available phosphorus. Soils of the Edalgo, the Elmo, and the Lancaster catenas are very low in total available phosphorus in both surface and subsoils.

Comparisons of exchangeable potassium content of the various soils indicated that soils of the Lockard, Rokeby catena were very high in exchangeable potassium. Exchangeable potassium content of soils for the Berg, Ebenezer, Niles catena was high to very high, and high for soils of the Edalgo, the Elmo, and the Lancaster catenas.

Cation exchange capacity results indicated that soils of the Edalgo catena had quite a low exchange capacity. All soils from the other catenas studied were moderately high, ranging from 15 to 32 m. e. per 100 gm. The exchange capacity of the Lancaster fine sandy loam surface soil was quite low; however, the subsoil cation exchange capacity was moderately high.

Yield results, by catenas, for all fertilizer treatments are summarized in Table 17. An evaluation of the data presented in this table brings to light several facts worthy of note:

1. Nitrogen applied singly gave response on the surface soils of the Berg, Ebenezer, Niles catena, while the response was very slight on the subsoils. Soils of the Edalgo, the Elmo, and the Lancaster catenas gave but slight response to nitrogen applied singly.

Table 17. Summary of grain yields of soils of Saline county, Kansas, by catenas.

Catena	Sample depth	Yield of grain in gm per pot: No treat.	N	P	K	NP	NK	PK	NPK
Berg, Ebenezer, Miles Catena									
Berg silt loam	0-12	7.03	14.46	6.33	8.35	17.82	13.85	6.00	18.35
Berg silt loam	12-30	1.09	1.16	1.48	1.28	21.00	1.37	12.52	20.30
Ebenezer silt loam	0-12	3.35	3.47	5.18	4.39	17.11	10.71	3.61	16.78
Ebenezer silt loam	12-30	1.66	1.58	0.60	0.51	20.32	1.34	1.45	16.17
Miles silt loam	0-15	3.37	6.33	9.09	4.05	16.11	9.18	3.79	19.03
Niles silt loam	15-30	1.82	1.21	1.89	1.75	26.98	0.18	1.42	19.53
Lockard, Rokeby Catena									
Lockard silt loam	0-14	3.35	4.72	3.33	3.14	19.44	18.45	4.12	19.71
Lockard silt loam	14-30	1.45	8.71	1.50	2.78	23.59	9.82	2.21	18.93
Rokeby silt loam	0-10	3.33	12.78	2.94	2.88	16.05	11.31	2.88	17.03
Rokeby silt loam	10-28	2.68	4.56	5.28	2.18	19.08	5.60	2.80	19.74
Edalgo Catena									
Edalgo silt loam	0-6	3.21	0.54	16.47	3.61	18.23	0.39	7.88	18.67
Edalgo silt loam	6-20	0.19	0.61	3.42	0.23	19.80	0.02	3.68	17.15
Lancaster Catena									
Lancaster loam	0-13	1.54	2.58	1.92	2.02	18.90	3.10	2.16	16.58
Lancaster loam	13-30	0.24	0.75	1.45	0.46	18.20	0.11	1.60	15.40

Table 17 (concl.).

Catena	Sample depth	Yield of grain in gm per pot: No treat.	N	P	K	NP	NK	PK	NPK
Lancaster Catena (cont.)									
Lancaster fine sandy loam	0-10	1.54	1.84	1.73	1.67	16.84	3.70	2.80	16.20
Lancaster fine sandy loam	10-28	0.87	0.20	1.92	0.78	17.42	0.15	1.83	17.06
Elmo Catena									
Elmo silt loam	0-11	1.37	4.99	1.80	1.83	18.36	4.61	2.02	17.21
Elmo silt loam	11-30	0.28	0.07	1.14	0.33	18.54	0.09	1.07	19.32

NOTE: Underscored values represent grain samples which were destroyed by mice. The missing values were predicted according to the regression of grain yield on straw yield graph, Fig. 1.

2. Phosphorus applied singly, apparently, gave but slight yield increases on the surface and subsoils of the Berg, Ebenezer, Niles catena. Soils of the Lockard, Rokeby catena apparently gave no response to phosphorus applied alone except for the subsoil of the Rokeby silt loam where a moderate response was noted. The surface soil of the member of the Idalgo catena gave a marked response to phosphorus applied singly with only a moderate response by the subsoil. Soils of the Lancaster and the Elmo catenas did not give an appreciable response to phosphorus applied singly.

3. Potassium gave no marked yield increases for any soil of the catenas studied.

4. Nitrogen and phosphorus applied in combination consistently gave very marked yield increases for all soils from all catenas studied. Subsoils, of all soils, were consistently more responsive to nitrogen and phosphorus applied in combination, than the surface soils.

5. Surface soils of the Berg, Ebenezer, Niles catena consistertly gave a response to nitrogen and potassium applied in combination. Subsoils consistently gave no response. All soils of the Lockard, Rokeby catena gave a response to applications of nitrogen and potassium in combination; however, the response of the subsoils was of lesser magnitude than that of the surface soils. Soils of the Elmo, the Idalgo, and the Lancaster catenas gave no response to very slight response to applications of nitrogen and potassium applied in combination.

6. In general, soils of the Berg, Ebenezer, Wiles catena gave no response to applications of phosphorus and potassium in combination. Likewise soils of the Lockard, Rokeby catena gave no response to phosphorus and potassium applied in combination. Soils of the Edalgo, the Elmo, and Lancaster catenas gave from no response to slight response to phosphorus and potassium applied in combination.

7. Nitrogen, phosphorus, and potassium applied in combination consistently gave very marked yield increases on all soils for all catenas studied.

SUMMARY AND CONCLUSIONS

The results of the fertility research project on some Saline and Jackson county soils, growing a crop of wheat, may be summarized as follows:

1. The application of nitrogen alone resulted in grain yield increases for many, but not all, of the soils studied.

2. The application of phosphorus alone resulted in grain yield increases for many, but not all, of the soils studied.

3. Potassium did not give a marked yield increase on any of the soils studied.

4. Very marked yield increases in grain yield resulted, irrespective of soil type, when nitrogen and phosphorus were applied in combination.

5. Very marked yield increases in grain yield resulted, irrespective of soil type, when nitrogen, phosphorus and potassium

were applied in combination. In no instance was any part of this yield increase attributable to potassium.

6. In general, chemical analyses indicated that the total available phosphorus content, for most of the soils studied, were low. All soils were found to be quite well supplied with exchangeable potassium.

7. Statistical analysis, contrasting grain yield with straw yield, gave a correlation coefficient of 0.9546. This high correlation allowed the prediction of the missing grain yields with a high degree of confidence.

8. Catena relationship studies indicated that, in general, soils of the Berg, Ebenezer, Niles catena and the Lockard, Rokeby catena might be considered as possessing a higher inherent fertility than soils of the Elmo, the Edalgo, and the Lancaster fine sandy loam catenas.

9. Catena relationship studies conclusively indicated that all soils, irrespective of catenas, consistently gave marked response to applications of nitrogen and potassium applied in combination.

10. Excellent agreement was established between plant growth response to phosphorus and chemically available phosphorus in the surface soils of Saline county. However, there was a definite lack of relationship between plant growth response and chemically available phosphorus in the subsoil, between plant growth response to nitrogen and organic matter content of the soil, and between plant growth response and exchangeable potassium content of the soil.

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THE EFFECT OF NITROGEN, PHOSPHORUS AND POTASSIUM
ON THE GROWTH OF WHEAT ON SOME SOILS
OF SALINE COUNTY, KANSAS

by

ROBERT ARTHUR BOHANNON

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A soil fertility study was conducted on 10 soil types from Saline county and 4 soil association groups from Jackson county. The purpose of the study was to determine whether these soil types would respond to applications of nitrogen, phosphorus and potassium applied singly and in all possible combinations. Growth response was studied by growing a crop of wheat and studying the differences in straw yields and grain yields resulting from the various fertilizer treatments.

Soil analyses were run on all soils prior to the growth of a crop of wheat. Soil analyses were also run on all soils involved in the fertility study after growth of the wheat crop. With this information, it was possible to study nutrient uptake by wheat under the various fertilizer treatments. Additionally, it was possible to determine whether heavy applications of fertilizer contributed to an appreciable build-up of the various elements applied, in the soil.

The greenhouse study was set up as a Factorial Design Experiment. A crop of wheat was grown to maturity and the weight of straw and grain was determined for each treatment. Response of the wheat to fertilizer applications was evaluated primarily from the grain yield data.

During harvest 27 grain samples were destroyed by mice. It was necessary to evaluate these missing grain yield values by utilizing the grain-straw ratio since the straw samples were not destroyed. A regression equation was determined which allowed the estimation of grain values from straw values. A correlation of 0.9546 was deemed sufficiently high to justify placing a relatively high degree of confidence on these estimated grain values.

The results of the fertility research project on some Saline and Jackson county soils, growing a crop of wheat, may be summarized as follows:

1. The application of nitrogen alone resulted in grain yield increases for many, but not all, of the soils studied.

2. The application of phosphorus alone resulted in grain yield increases for many, but not all, of the soils studied.

3. Potassium did not give a marked yield increase on any of the soils under study.

4. Very marked yield increases in grain yield resulted, irrespective of soil type, when nitrogen and phosphorus were applied in combination.

5. Very marked yield increases in grain yield resulted, irrespective of soil type, when nitrogen, phosphorus and potassium were applied in combination. In no instance was any part of this yield increase attributable to potassium.

6. In general, chemical analyses indicated that the total available phosphorus content, for most of the soils studied, was low. All soils were found to be quite well supplied with exchangeable potassium.

7. Statistical analysis, relating grain yields to straw yields, gave a correlation coefficient of 0.9546. This high correlation allowed the prediction of the missing grain yields with a high degree of confidence.

8. Catena relationship studies indicated that, in general, soils of the Berg, Ebenezer, Niles catena and the Lockard, Rokeby catena might be considered as possessing a higher inherent fertility than soils of the Elmo, the Hidalgo, and the Lancaster fine sandy loam catenas.

9. Catena relationship studies conclusively indicated that all soils, irrespective of catenas, consistently gave marked response to applications of nitrogen and phosphorus applied in combination.

10. Excellent agreement was established between plant growth response to phosphorus and chemically available phosphorus in the surface soils of Saline county. However, there was a definite lack of relationship between plant growth response and chemically available phosphorus in the subsoils, between plant growth response to nitrogen and organic matter content of the soil, and between plant growth response and exchangeable potassium content of the soil.