May 12, 1938

To the Committee on Graduate Study:

I submit herewith a thesis written by Mr. Haskell Cordell Phillips and entitled " Response of Putnam County Soils to Phosphate Fertilizer", and recommend that it be accepted for nine quarter hours credit in partial fulfillment of the requirements for the degree of Master of Science with a major in Agriculture.

R. H. Burris
Major Professor

At the request of the
Committee on Graduate Study,
we have read this thesis,
and recommend its acceptance.

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Accepted for the Graduate Committee

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Dean

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Haskell Phillips

RESPONSE OF PUTNAM COUNTY SOILS TO PHOSPHATE FERTILIZER

- o -

A THESIS

Submitted to the Graduate Committee
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

by

HASKELL CORDELL PHILLIPS

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CONTENTS

PAGE

I. INTRODUCTION 1

II. PHOSPHATE EXPERIMENTS IN THE VARIOUS STATES

CONNECTICUT: Pasture, lime, nitrogen, phosphoric acid, potash, sulphate of ammonia. 4

VIRGINIA: Alfalfa, acid phosphate, barnyard manure, corn, raw rock phosphate, peanuts, tobacco, wheat 5

KENTUCKY: Corn, oats, clover, soy beans, wheat, rock phosphate, muriate of potash, acid phosphate, peas, sulphate of potash, limestone, tobacco, potatoes, clover. 15

INDIANA: Corn, soy beans, wheat, hay, superphosphate, potash, nitrogen, lime, manure, comparisons of phosphates: Steamed bone meal, basic slag, superphosphate, rock phosphate . . 22

PENNSYLVANIA: Corn, oats, wheat, mixed clover and timothy hay, lime, phosphoric acid, muriate of potash, dried blood, nitrate of soda, sulphate of ammonia. 27

WISCONSIN: Oats, manure, acid phosphate, corn, corn silage, pasture, oats, barley, alfalfa, clover, superphosphate. 31

TENNESSEE: Millet, acid phosphate, nitrate of soda, corn, phosphate, nitrate of soda, muriate of potash, farmyard manure, sorghum, acid phosphate, muriate of potash, cotton-seed meal, cowpeas, lime, acid phosphate, Thomas slag, bone meal, rock phosphate, wheat, lime, Thomas slag, steamed bone meal, acid phosphate, rock phosphate, Irish potatoes, manure, acid phosphate, nitrate of soda, tobacco, acid phosphate, lespedeza, acid phosphate, ground limestone, corn, cow peas, clover, wheat, cotton, acid phosphate, ... 38

NEW HAMPSHIRE: Alfalfa, limestone, manure, superphosphate, potash, tomatoes, acid phosphate, manure. 47

MONTANA: Alfalfa, treble superphosphate, wheat, treble superphosphate, ammoniated phosphate, oats, treble superphosphate, oats, barley, canning peas, mustard, Irish potatoes, sugar beets, treble superphosphate. 49

FLORIDA: Hairy vetch and Austrian peas, superphosphate. 52

154340

26 Oct 38 M.B. 90

PAGE

GEORGIA: Sweet potatoes, superphosphate, cotton, superphosphate, Florida pebble rock phosphate, Tennessee brown rock phosphate, Tennessee blue rock phosphate, Florida soft rock phosphate. . 53

MICHIGAN: Potatoes, superphosphate. 54

MISSISSIPPI: Alfalfa, superphosphate, basic slag, manure. 55

IOWA: Corn, oats, clover and timothy and wheat, manure, lime, rock phosphate, superphosphate, complete fertilizer. 56

ALABAMA: Vetch, superphosphate, cotton, superphosphate, cotton-seed meal, complete fertilizer. 57

III. EFFECT OF PHOSPHORUS ON PLANT DEVELOPMENT. 60

IV. DIAGNOSING PHOSPHORUS DEFICIENCIES OF A SOIL. . . . 61

V. OBJECTIVE OF THE EXPERIMENT. 62

VI. LOCATION OF THE EXPERIMENT. 62

VII. METHODS EMPLOYED IN THE EXPERIMENT

FERTILIZER TREATMENTS: Nitrate of soda, calcium metaphosphate, muriate of potash, watering. . 63

VIII. THE SOILS: Laboratory tests, descriptions, locations, history. 67

IX. DISCUSSION OF RESULTS: Growth of plants, blossoms, fruit, roots. 72

X. SUMMARY 81

XI. BIBLIOGRAPHY 82

TABLES IN TEXT

Table — Page

I. Fertilizer Tests on Alfalfa and Pounds of Alfalfa Hay Harvested for the Years Indicated.....7

II. Rotation Fertilizer Test With Corn at Blackbury.....8

III. Results of Fertilizer Experiments on Corn on Piedmont Gray Soils at Chatam.....10

IV. Effect of Fertilizers on Yield of Peanuts at Holland.....11

V. The Effects of Different Fertilizers on the Value of Bright Tobacco Produced and the Residual Effects of the Same Fertilizers on Crops Subsequently Grown in Rotation on the Same Land Without Additional Fertilizer Treatment.....12

VI. Fertilizer Rotation Test With Wheat at Blackbury.....14

VII. Yields per Acre of Various Crops Receiving Different Fertilizer Treatments, Burnside Experiment Field.....17

VIII. Crop Yields Per Acre from Various Fertilizer Treatments, Lexington Soil Experiment Field.....20

IX. Tobacco, Potato, and Clover Yields, per acre, on the Greenville Experiment Field from Various Fertilizer Treatments..21

Table Page

X. Average Yields and Financial Statement, Per Acre, Per Rotation, of the Indiana Experiment.....24

XI. Average Yields and Financial Statement per acre, Per Rotation, from Various Phosphate Treatments.....26

XII. Average Annual Yields of Crops on Hagerstoan Silt Loam Receiving Various Fertilizer Treatments (1882-1921).....29

XIII. Acre Yields of Oats with and Without Phosphate Fertilizer.....32

XIV. Effect of Phosphate Fertilizer on Wisconsin Corn.....33

XV. Relation Between Available Phosphorus and Yields of Dry Matter Taken at Grazing Stages by lawn Mower Clippings.....35

XVI. Average Yields Per Acre in Trials with Phosphate Fertilizer in Wisconsin.....37

XVII. Fertilizer Experiments with Millet Grown on Middle Tennessee Soils.....39

XVIII. Fertilizer Experiments with Corn in Warren County.....42

XIX. Fertilizer Experiments with Irish Potatoes on the Cumberland Plateau-- Yields Per Acre.....46

XX. Results of the Cunninghamilla Plaque Test for Available Nitrate in Soil.....68

XXI. Results of the Cunninghamilla Plaque Test for Available Phosphorus in Soil.....68

XXII. Results of the Aspergillus Niger Test for Available Potassium in Soil.....69

Table Page

XXIII. Results of Truog Reaction Test.....69

XXIV. Height of plants in Inches, 42 and 93 days after Transplanting.....74

XXV. Date of First Blossom.....75

XXVI. Date First Fruit Was Set.....76

XXVII. Number of Blossoms.....76

XXVIII. Number of Fruit Set.....76

M A P S

Page

I. Putman County Showing Location of Soils.....64

FIGURES

Page

1. Yields on plots receiving single fertilizer ingredients, in total pounds per acre, in a rotation at the Pennsylvania Station.....30

2. Factors most frequently found to be the cause of low crop yields and poor plant cover.....59

3. University of Tennessee greenhouse.....62

4. Plants of the A series 42 days after transplanting.....77

5. Plants of the B series 42 days after transplanting.....77

6. Plants in soil 1 42 days after transplanting...78

7. Plants in soil 2 42 days after transplanting...78

8. Plants in soil 3 42 days after transplanting...79

9. Plants in soil 4 42 days after transplanting...79

10. Plants in soil 5 42 days after transplanting..80

11. Roots of plants 93 days after transplanting...90

INTRODUCTION

Putnam county is located in the north central part of Tennessee. It is bounded on the north by Jackson and Overton Counties, on the east by Fentress and Cumberland Counties, on the south by White and DeKalb Counties, and on the west by Smith County. It includes parts of three of the natural geographical divisions of Tennessee; nanely: The Cumberland Plateau, the Highland Rim, and the Central Basin. The major part of the County lies within the Highland Rim. It has an approximate area of 258,560 acres.

The average elevation of the Cumberland Plateau is approximately 1800 feet above sea level. That of the Highland Rim is about 900 feet, or nearly 300 feet above the Central Basin.

The major part of the County is hilly to gently undulating; however, there are areas which are practically level. Some of the land is too rough to be of importance in the production of cultivated crops.

The soils of the County may be divided, roughly, into the following types: The DeKalb sandy loams, in the Cumberland Plateau section; the red-colored silt loams, the "Barrens" silt loams, and the light gray silt loams or "Crawfishy", all of which are in the Highland Rim; and the gravelly loams of the Central Basin.

The DeKalb series is derived from siliceous and shale formations. They are fine sandy loams and have good retentive

subsoils. Much of the area is shallow in depth, the rock often showing at the surface. Chemical analysis and crop experiments have shown this series to be very deficient in both phosphoric acid and lime. Chemical analysis have shown these soils to be deficient in potash, but crop experiments have shown only moderate returns from the application of potash fertilizers.

The red-colored silt loams are the most fertile of the Highland Rim soils. They contain a fair supply of potash, but are low in phosphoric acid. If properly managed, clover and grasses can be grown successfully on these soils. They are of limestone origin, but are low in lime.

Soils of the "Barrens" type are derived largely from siliceous formations. They are among the poorest and most difficult to handle. This type is very poor in phosphoric acid, potash, lime, and nitrogen. Without the use of phosphate profitable crop production is very difficult. Potash also aids in producing good crops on these soils.

The chief difference between the "Barrens" and the "Crawfishy" soils is that the latter is poorly drained.

Only a small part of the County is occupied by the Central Basin. Better Crops are produced on the soils in this area than on those previously described. Chemical analysis have shown that most of them have a fair supply of all the plant food elements where proper management has been exercised.

An excerpt[1] of the Chemical analyses of soils belonging to the above series is as follows:

ANALYSES OF TENNESSEE SOILS

Section and kind of soil	County	Per cent Potash	Per cent Phosphoric acid	Per cent Nitrogen
Cumberland Plateau				
Sandstone	Cumberland	0.080	0.028	0.085
Highland Rim				
Limestone	White	0.220	0.070	0.080
Barrens	Putnam	0.070	0.032	0.070
Central Basin				
Limestone	Smith	0.222	0.215	0.079

Corn is the most extensively grown cultivated crop in Putnam County. Other important crops are lespedeza, wheat, sorghum, oats, clover, and timothy. Crops of minor importance, from the standpoint of acreage are barley, alfalfa, tobacco, Irish potatoes, and sweet potatoes.

Very little experimental work has been done with Putnam County soils. A few cooperative field experiments have been made in some parts of the County, the object of which was to determine the effects of fertilizers upon crops grown in soils in this section of Tennessee.

Only a small number of chemical analyses have been made of the soils in this area; and as yet, no detailed survey has been reported.

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1. Tennessee Agricultural Experiment Station Bulletin No. 78, Vol. XIX. No. 4, "The Soils of Tennessee Their Chemical Composition and Fertilizer Requirements", 1906, pp. 86-88.

PHOSPHATE EXPERIMENTS IN THE VARIOUS STATES

CONNECTICUT

At the Storrs Experiment Station[2], in 1919, was started a fertilizer experiment on pasture plots. The plant nutrients that were used were lime, nitrogen, phosphoric acid, and potash. In the spring of 1924, the nutrients were added at the following rates in pounds per acre: Ground limestone, 2,000; superphosphate (16%), 500; muriate of potash, 100; nitrate of soda, 150. During the next five years the only fertilizers that were applied were either nitrate of soda or a mixture of nitrate of soda and sulphate of ammonia which was applied annually.

It was found during the second year of the experiment that no noteworthy improvement had resulted from any of the fertilizer combinations that did not contain phosphate. It was also noted that when either limestone or nitrogen carrying fertilizers were added in addition to phosphate that there was a decided increase in plant growth. Expressed in terms of the untreated plots, the addition of superphosphate increased the pasture production 80%. If clover hay were worth $13.50 per ton and corn silage $6.00 per ton, the value of these feeds that could be replaced by one acre of pasture, each year, receiving no treatment, and the superphosphate treatment would

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2. Connecticut State College Agricultural Experiment Station Bulletin 190, "Pasture Investigation (Fifth Report) A Resume of Thirties Years of Research", 1933, pp. 3-5.

be $9.18 and $16.53 respectively. This shows an increased value of $7.35. The annual cost of fertilizer was $0.94. This gave a net return of $6.41 per acre each year for merely adding phosphate fertilizer.

VIRGINIA

One of the chief fertilizer requirements for growing alfalfa successfully in Virginia is phosphate.[3] In this state phosphorus can most economically be supplied in the form of acid phosphate and basic slag. Not less than 500 pounds of acid phosphate, or its equivalent, is recommended per acre for alfalfa in this state. Occasionally, as much as 1000 pounds per acre has been added at the time of seeding with paying results.

In 1912 some experiments were started to determine the fertilizers that should be used to grow alfalfa most successfully. The soil which was used for the purpose was a fine sandy loam. Before the experiment was started, the soil was in broom sedge, briars, and scrub pines. Corn, beans, and oats were grown for two years before the land was seeded to alfalfa. No manure or lime was used on the preceding crops mentioned, but they did receive light applications of acid phosphate.

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3. Virginia Agricultural Experiment Station Bulletin 221, "Fertilizers and Their Relation to Crop Production in Virginia", 1919, pp.22-70.

Table I shows the results obtained over a six year period.

> The results here tabulated represents pounds per acre of field cured hay. The two most striking features of the results obtained are the benefits derived from phosphorus and barnyard manure, which may be seen by reference to Table I. The results from the use of phosphorus are consistent all through the tests.
>
> Taking the individual plats and making a summary of these seedings over a period of six seasons it is seen that 16% acid phosphate alone has given practically double the yield of hay as that obtained from nitrate of soda or muriate of potash alone.
>
> The hay obtained from plats to which either manure or acid phosphate alone was applied or when the two were applied in combination, was not only more in quanity but was freer from weeds and of better quality.[4]

Corn-- The value of phosphate fertilizer has been shown on the soils of Western Virginia. These soils are mostly of limestone origin. They contain a sufficient amount of potash to produce good corn crops if proper soil management practices are followed, such as the addition of lime once in five years, and a feasible rotation is used. If legumes are included in the rotation, nitrogen fertilizers are not needed. Soils in this region, as well as in other sections of the state, are decribely low in phosphorus. A recommended rotation for this section is : First year, corn; second year, wheat; third and fourth years, clover and grasses.

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4. Virginia Bulletin 221., op. cit. p. 24.

Table I. FERTILIZER TESTS ON ALFALFA AND POUNDS OF ALFALFA HAY HARVESTED FOR THE YEARS INDICATED

Fertilizer applied per acre	Seeded 1912		Seeded 1913		Seeded 1915		
	1913	1914	1914	1915	1916	1917	1918
333 lbs. nitrate of soda	5,455	2,670	1,660	2,420	4,840	1,040	480
800 lbs. acid phosphate	6,452	2,880	5,014	5,060	8,300	5,380	2,560
200 lbs muriate of potash	4,832	2,570	2,060	2,060	5,480	1,900	900
No fertilizer	3,912	2,440	1,840	2,320	5,560	1,720	860
800 lbs. acid phosphate; 200 lbs. muriate of potash	7,650	3,650	4,880	6,060	10,260	7,300	2,940
333 lbs. nitrate of soda; 200 lbs. muriate of potash	5,812	2,860	2,760	3,120	7,000	2,960	1,360
333 lbs. nitrate of soda; 800 lbs. acid phosphate	8,008	3,790	4,380	5,160	10,640	7,040	3,386
333 lbs. nitrate of soda; 800 lbs acid phosphate; 200 lbs. muriate of potash	9,220	3,980	4,980	5,480	11,900	7,200	3,620
No fertilizer	4,800	2,880	2,080	2,760	6,720	2,480	1,080
10 tons barnyard manure	11,136	4,920	7,500	6,420	11,400	5,860	2,420
10 tons barnyard manure; 400 lbs. acid phosphate	12,000	5,320	8,620	8,520	12,680	6,800	3,280
500 lbs. pure raw bone meal	5,940	2,980	3,480	4,380	5,800	2,660	1,300
700 lbs. acid phosphate	6,848	3,320	3,940	4,120	6,400	3,560	1,800
600 lbs. basic slag	6,264	3,250	3,240	4,360	5,620	3,240	1,820

In 1909 an experiment was started in the above described soils using the previously mentioned rotation; it was conducted until 1916. The purpose of the experiment was to show the response of corn, grown in a definite rotation in these soils, to different fertilizer treatments. Results of the experiment are given in Table II.

Table II. ROTATION FERTILIZER TEST WITH CORN AT BLACKSBURY

Treatment	Average yield in bushels per acre	Average increase for use of fertilizer
219 lbs. acid phosphate	59.38	14.15
100 lbs muriate of potash	48.74	3.51
150 lbs. dried blood	41.26	- 3.97(loss)
409 lbs. floats	42.95	- 2.28 "
4 tons manure annually	65.52	20.29
16 tons manure once in 4 years before corn	61.94	16.71
200 lbs acid phosphate 100 lbs. muriate of potash	55.99	10.76
219 lbs acid phosphate 154 lbs. dried blood	57.06	11.83
100 lbs. muriate of potash 154 lbs dried blood	50.01	4.78
219 lbs acid phosphate 100 lbs muriate of potash 154 lbs dried blood	61.41	16.18
No fertilizer	45.23	.....

> An examination of the data presented in Table II shows that in those experiments under the rotation mentioned that acid phosphate was the only commercial fertilizer that gave paying results. When floats (raw rock phosphate)was used as a source of phosphorus, it is not used on an equal money value basic with acid phosphate, but both materials were used at the rate of 35 pounds of actual phosphoric acid to the acre. It should be borne in mind that these experiments were made on a limestone soil, and in a rotation where red clover, a legume, came once in four years, and a sod was turned down before corn each year. These soils are usually rich in potash and the nitrogen and humus were maintained, in this case, by the legume and the sod. This leaves phosphorus as the only element, which is usually deficient in Virginia soils, that was necessary for maintaining crop yields.[5]

In the gray soils of the Piedmont section, and experiment was carried out with corn grown on land preceded by other crops to which fertilizer had been added to determine the residual effect of different fertilizers. Fertilizers were applied only to the tobacco crop. This was followed by: First year, wheat; second and third year, grass and clover; fourth year, corn. Data from this experiment is shown in Table III.

From Table III it can be seen readily that acid phosphate gave the greatest and most profitable returns. Another presentation is that even after four years of cropping with no additional application of fertilizer, the heavy application of phosphate still exerted itself.

5, Virginia Bulletin 221., op. cit. p. 30.

Table III. RESULTS OF FERTILIZER EXPERIMENTS ON CORN ON PIEDMONT GRAY SOILS AT CHATHAM.

Kind and quantity of fertilizer applied per acre	Yield in bushels per acre
Sulphate of potash, 200 lbs	32.6
Dried blood, 375 lbs	30.3
Acid phosphate, 700 lbs	54.3
Acid phosphate, 700 lbs. Sulphate of potash, 200 lbs	52.0
3-8-3 Commercial fertilizer, 800 lbs	41.7
3-8-3 Commercial fertilizer, 1400 lbs	49.7
Check---no fertilizer	31.4

Peanuts.-- In Virginia commercial production of peanuts is limited to the sandy soils in the southeastern section of the state. Soils of this class are deficient in available plant food elements. It has been found here that peanuts grow better if included in a rotation and the fertilizer is applied to some preceding crop rather than to the peanut crop itself.

In 1914 an experiment was started with peanuts at the Holland Station to determine the response of the crop to different fertilizer treatments. The rotation which was used is as follows: First year, corn, with crimson clover used as a cover crop; second year, peanuts; third year, cotton; fourth year, soybeans. In this rotation fertilizers were applied

only to the corn and cotton crops. Effect of different treatments, as indicated by the yield of peanuts, is shown in Table IV.

Table IV. EFFECT OF FERTILIZERS ON YEILD OF PEANUTS AT HOLLAND

Amount of fertilizers per acre	Pounds of unhulled nuts per 1/20--acre plat				
	1914	1915	1916	1917	Av. for 4yrs.
240 lbs. dried blood	77	59	74	28	60
500 lbs. acid phosphate	68	84	83	33	67
200 lbs. muriate of potash	80	58	80	34	63
Check	70	35	71	25	50
240 lbs. dried blood; 200 lbs. muriate of potash	75	70	88	32	66
500 lbs. acid phosphate; 200 lbs. muriate of potash	88	63	95	35	70
500 lbs. acid phosphate; 240 lbs. dried blood	120	60	98	27	76

Acid phosphate and some form of potash containing fertilizers have given good results. Applications of 500 pounds of 16% acid phosphate and 200 pounds of muriate of potash are recommended.[6]

Poor yields in 1917 were attributed to excessive rainfall.

6. Virginia Bulletin 221., op. cit. p. 48

Tobacco.-- In 1912 an experiment was started at Chatham, Virginia to determind the best fertilizer for bright tobacco and also its effect upon succeeding crops. Tobacco was grown in a five year rotation: First year, tobacco; second year, wheat; third and fourth years, mixed grasses; fifth year, corn. Fertilizer applications were made only to the tobacco crop. In this way the residual effects of different plant food materials could be determined. Results are shown in Table V.

Table V THE EFFECTS OF DIFFERENT FERTILIZERS ON THE VALUE OF BRIGHT TOBACCO PRODUCED AND THE RESIDUAL EFFECTS OF THE SAME FERTILIZERS ON CROPS SUBSEQUENTLY GROWN IN ROTATION ON THE SAME LAND WITHOUT ADDITIONAL FERTILIZER TREATMENT

Rate per acre	1912 Tobacco	1913 Wheat bu.	1914 Mixed grasses lbs.	1915 Mixed grasses lbs.	1916 Corn. bu.
375 lbs. Dried Blood	$19.36	5.5	20	480	25
700 lbs. Acid phosphate	64.25	8.	2160	2160	49.7
200 lbs. Sulphate of potash	30.68	5.5	280	960	35.4
700 lbs. Acid phosphate; 200 lbs. Sulphate of potash	63.90	8.5	2680	2080	45.1
375 lbs. Dried blood; 200 lbs. Sulphate of potash	26.49	3.5	40	480	16.

Table V. (Continued)

375 lbs. Dried blood 700 lbs. Acid phosphate	37.25	9.5	440	1360	32.6
Check No fertilizer	8.00	3.3	40	400	16.3

In no case, however, are the after effects very noticeable except on plats where phosphates are used.

The phosphates have given good results for the succeeding four years in increased yields of wheat, grass (two years) and corn, after which the land was again put in tobacco.

Phosphoric acid is the most generally needed plant food material in the bright tobacco section, and a liberal application of phosphate should be used not only on tobacco but on all crops grown in the rotation with tobacco. Phosphoric acid not only increases the yield and improves the quality, but is a very important factor in brightening the color. It also hastens maturity which in bright tobacco is very desireable. Acid phosphate is probably the best source of phosphorus for bright tobacco.[7]

Wheat.-- The wheat area of Virginia is found in the western portion of the state. These soils are usually deficient in phosphate. If legumes are grown in a rotation, and lime and phosphates are added, fairly good crops can be expected. If a good rotation system is followed, 200 to 400 pounds of acid phosphate is recommended for wheat, the application to be made at the time of seeding. Providing the rotation is not satisfactory or the land is poor, a 3-10-2 fertilizer should be used.

7. Virginia Bulletin 221., op. cit. p. 56.

A recommended rotation, for wheat, is : First year, corn; second year, wheat; third year, clover; fourth year, grass.

At Blacksbury, in 1909, a six year trial was started with wheat, grown in the above mentioned rotation, to determine the most economical and best fertilizer for this crop. Fertilizers were applied annually. Results secured are shown in Table VI.

Table VI. FERTILIZER ROTATION TEST WITH WHEAT AT BLACKSBURY

Treatment	Average yield in bu. per acre (1909-1916)	Average increase for use of fertilizer
219 lbs. acid phosphate	14.17	6.34
100 lbs. muriate of potash	11.54	3.71
154 lbs. dried blood	7.89	.06
109 lbs. floats	8.55	.72
4 tons manure annually	18.31	10.48
16 tons manure once in 4 years before corn	17.54	9.71
219 lbs. acid phosphate; 100 lbs. muriate of potash	14.83	7.00
219 lbs. acid phosphate; 154 lbs. dried blood	13.54	5.71
100 lbs. muriate of potash; 154 lbs. dried blood	10.28	2.45
219 lbs. acid phosphate; 100 lbs. muriate of potash; 154 lbs. dried blood	14.65	6.82
No fertilizer	7.83	----

The conclusion reached at the end of the experiment was that acid phosphate was the only commercial fertilizer that gave paying results. Increased yields made by potash and nitrogen was usually not enough to pay for the fertilizer used. It is stated that the above test for raw rock phosphate was not a fair one due to the fact that phosphate in this form is so slowly available that not enough of the pland food element is conveyed to the crop, in the soil solution, during any one season to meet the requirements of the plants. It is further stated that acid phosphate is the most economical source of phosphate for wheat.

KENTUCKY

In 1913 the Kentucky Agricultural Experiment Station[8] inaugurated a system of field experiments in order to determine the best methods to use in increasing and maintaining productiveness on the various soils of that state. For this purpose fields were selected in various parts of the State that would represent a more or less large section of soil in that area.

At Burnside, in 1908, an experiment was started on an exceptionally unproductive soil, the unproductivity being due to uniform washing and continued cultivation. This particular portion of the field was described as being so poor that many

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8. Kentucky Agricultural Experiment Station Bulletin 199, "Soil Experiment Fields--A Progress Report", 1916 pp.43-78.

times when an attempt was made to grow corn on it the growth was not sufficient to warrant harvesting. The soil was of limestone origin and had a red clay subsoil. Crops used were: First year, corn; second year, oats; third year, clover (one crop cut for hay); fourth year, corn, followed by rye cover crop; fifth year, soy beans; sixth year, wheat followed by cowpea catch crop; seventh year corn.

Fertilizers were applied to the cowpea,1908, which preceded the corn crop. Rock phosphate was applied at the rate of 2,000 pounds per acre, muriate of potash 400, and acid phosphate 800 pounds. The same fertilizer application was made preceding the 1912 corn crop as was made in 1908. In 1911 manure was added to the clover crop to the approximate the plant food removals of the two preceding crops. Results of this experiment are shown in Table VII.

Prices that were used in making these calculations were: Corn, 60 cents per bushel; oats, 40 cents per bushel; wheat, 90 cents per bushel; all hay, $12.00 per ton; acid phosphate, 80 cents per 100 pounds; potash, $2.75 per 100 pounds; raw rock phosphate at $6.40 per ton.

> Plot No. 5 is not to be considered a check plot. A large part of it is lower ground that has for many years been receiving washings from the ground around it, and is for this reason more productive than the other plots. It is included to show that poorer ground by proper treatment may be made to surpass it in fertility.[9]

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9. Kentucky Bulletin 199., op. cit. p. 49.

Table VII. YIELDS PER ACRE OF VARIOUS CROPS RECEIVING DIFFERENT FERTILIZER TREATMENTS, BURNSIDE EXPERIMENT FIELD

Treatment	Corn, bu.	Oats, bu.	Clover, lbs.	Corn, bu.	Soy bean hay, lbs.	Wheat, bu.	Corn, bu.	Value of crops	Total cost of fertilizer	Value of Increase less fertilizer cost
1. Rock phosphate and potash	3.8	9.3	2436	32.9	1688	11.9	34.8	$82.07	$30.45	$23.95
2. Nothing	9.0	9.0	668	9.5	628	2.5	4.9	27.68	0.00	0.00
3. Acid phosphate and potash	14.3	11.9	2168	45.7	2272	19.2	46.6	112.64	30.45	54.52
4. Acid phosphate	17.7	13.6	2328	43.5	2112	18.1	50.9	115.63	11.20	76.76
5. Nothing	20.4	14.0	1292	30.3	1176	5.1	18.5	66.52	0.00	0.00
6. Potash	11.9	10.5	764	17.6	560	1.7	5.3	34.55	19.25	- 12.37

Conclusions were drawn from this experiment that there was a slight increase in the fertility of plots 1 to 4 inclusive. No material improvement was made on any of the plots which did not receive phosphate in some form. Potash caused very little increase in yield. It seemed that acid phosphate was worth more on this soil, dollar for dollar, than raw rock phosphate.

Peas grown on plots that were not supplied with acid phosphate averaged about 12 inches high, while on those plots to which acid phosphate was added the peas averaged about 24 inches. Peas on the plots receiving acid phosphate developed twice as many nodules as those grown on other plots although the plots were all inoculated alike by the soil method.

Total chemical analysis of this field showed: Nitrogen, 1400 pounds; phosphate, 666 pounds; potash, 12,200 pounds per acre of soil seven inches deep.

Corn, soy beans, wheat, and clover.-- A series of experiments were started at the Lexington Experiment Station to determine the response of the above named crops to fertilizers. The soil on which these trials were made were of the Trenton limestone formation. Soils of this type are exceptionally high in phosphorus, containing on an average 9000 pounds per acre in the top seven inches, some containing as much as 20,000 pounds. Total analyses of the soil used in this experiment showed; Nitrogen, 4480 pounds;

phosphorus, 10,000 pounds; and potassium, 28,00 pounds per acre.

The rotation followed consisted of: First year, corn followed by cow peas or crimson clover; second year, soy beans; third year, wheat and clover; fourth year clover.

Acid phosphate was applied at the rate of 800 pounds per acre, sulphate of potash 500 pounds per acre, and limestone four tons per acre. Application was made once in four years, corn being the crop to which the fertilizer was added.

A summary of the results obtained from the experiment is shown in Table VIII.

> A study of the yields shows that there has been no consistent or decided effect from any of the fertilizing materials applied.
>
> We believe it is a safe conclusion that the use of phosphates and potash is not necessary on well drained, highly phosphatic soils of the Trenton limestone formation when organic matter is maintained in quantities to furnish the necessary nitrogen for good crop yield.[10]

Tobacco, potatoes, and clover.-- At the Greenville Experiment Field fertilizer trials were made on a tobacco-potatoes-clover rotation. Treatments and results of this experiment are given in Table IX.

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10. Kentucky Bulletin 199., op. cit. p. 62.

Table VIII. CROP YIELDS PER ACRE FROM VARIOUS FERTILIZER TREATMENTS, LEXINGTON SOIL EXPERIMENT FIELD

Treatment	Corn, bu. (Av. 1911-1915)	Soy beans, bu. (Av. 1912-1915)	Wheat, bu. (Av. 1913-1915)	Clover hay, lbs. (Av. 1914-1915)
Acid phosphate	42.2	21.2	26.7	4500
Potash	41.3	22.1	26.5	4980
No treatment	45.0	21.5	26.0	5250
Acid phosphate and potash	43.0	21.7	27.7	5040
Acid phosphate and potash	45.0	21.3	28.9	4830
Limestone and acid phosphate	47.6	22.1	28.9	5250
Limestone and potash	51.8	22.1	27.5	4560
Limestone	52.9	21.5	28.5	5160
Limestone acid phosphate and potash	53.9	25.9	31.8	4860
No treatment	53.7	25.3	27.7	4620
Acid phosphate	50.1	23.6	26.7	4620
Potash	51.4	23.0	27.1	5060

Table IX. TOBACCO, POTATO, AND CLOVER YIELDS, PER ACRE, ON THE GREENVILLE EXPERIMENT FIELD FROM VARIOUS FERTILIZER TREATMENTS

Treatment	Tobacco, lbs. 1914	Potato, bu. 1915	Clover, lbs. 1914	Clover, lbs. 1915
1. Limestone and acid phosphate	1235	69.7	2300	5360
2. Limestone and potash	760	43.1	None	1085
3. Limestone, acid phosphate, and nitrogen	1595	100.7	2150	4860
4. No treatment	575	39.1	None	590
5. Limestone, potash, and nitrogen	580	42.2	None	740
6. Limestone, acid phosphate, potash, and nitrogen	1410	107.4	3010	5450
7. Acid phosphate, potash, and nitrogen	1625	135.4	2750	4420

Acid phosphate was used at the rate of 200 pounds per acre; sulphate of potash, 100 pounds per acre; nitrate of soda, 100 pounds per acre. All applications were made annually excepting nitrate of soda which was applied only to the tobacco and potato crops. Limestone was applied at the rate of four tons per acre at the beginning of the experiment.

Increase in yield was slight in all cases whenever phosphate was not added. Although the increase due to potash was slight it is stated that it materially improved the quality of the tobacco crop.

The low yields of the clover crop, in 1914, on plots 1 and 3 were due to a thin stand.

INDIANA

Corn, soy beans, wheat, and hay[11]-- For the purpose of fertilizer experimentation with poor soils in Indianna, ten acres of poor pasture land was selected in the southern part of the state. The soil was described as being yellowish-brown silt loam, typical of a large section of land in that area.

The origional rotation, started in 1917, consisted of corn, wheat, clover, and timothy. In 1923 this was changed to corn, soy beans, wheat, and clover. In plots 6, 7,8,10 and 11 all of the crop was left as a residue excepting the ear corn, wheat grain, soy bean grain, and clover hay. Fertilizer were applied at the following rates per acre: Phosphoric acid, 72 pounds; potash, 24 pounds; nitrogen, 12 pounds per rotation. Until 1928 the phosphorus and potash were divided equally between the corn and wheat,

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11. Indiana, Purdue University, Agricultural Experiment Station Circular 172, "Report of MOSES FELL Annex Farm," 1930, pp.3-6.

the nitrogen all being applied to the wheat crop. Lime was applied at the rate of three tons per acre in 1917. Manure was applied to the corn crop each year at the rate of six tons per acre.

Results of this experiment are summarized in Table X. Values used in Table X computations were: Corn, $0.60 per bushel; wheat, $1.25 per bushel; soy beans, $1.25 per bushel; stover and wheat straw, $2.50; soy bean straw, $3.00; and hay at $10.00 per ton. Nitrogen, phosphoric acid, and potash were charged at 20, 7, and 6 cents per pound respectively. Limestone was valued at $3.50 per ton.

> Phosphorus is by far the most important plant food need of this soil. Applications of superphosphate have been highly profitable, either alone or in addition to manure. Without manure (plot 2) 225 pounds of 16 percent superphosphate for corn and wheat in the four-year rotation have produced average crop increases of 16.9 bushels of corn, 6.9 bushels of soy beans, 6.8 bushels of wheat and 1,159 pounds of hay per acre, valued at $36.85 for the rotation at a cost of $5.04 for the fertilizer. On land receiving an average of 6.8 tons of manure for corn, a similar use of superphosphate has further increased the crop yields by 10.1 bushels of corn, 5.9 bushels of soy beans, 5.8 bushels of wheat and 1,202 pounds of hay worth $30.13 at a cost of $5.04 for the phosphate, showing that manure is not sufficient on this land.[12]

Comparison of different phosphates.[13] -- At the Bedford Experiment Farm comparisons of different phosphates in terms

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12. Indiana, Purdue University Circular 172, op. cit. p. 4.

13. Indiana, Purdue University Circular 172, op. cit. pp. 7-8.

Table X. AVERAGE YIELDS AND FINANCIAL STATEMENT, PER ACRE, PER ROTATION, OF THE INDIANA EXPERIMENT

Treatment	Corn, bu. (Av. 1917-1929)	Soy beans, bu. (Av. 1923-1929)	Wheat, bu. (Av. 1918-1929)	Hay, lbs. (Av. 1917-1929)	Total value four crops	Value of increase	Cost of fertilizer	Net gain due to fertilizer
1. Lime	23.8	9.7	4.8	1369	$45.49	---	---	---
2. Lime and phosphorus	41.2	16.7	11.7	2543	82.83	$36.85	$ 5.04	$31.81
3. Lime, phosphorus, and potash	45.0	16.2	12.0	2478	84.55	38.06	6.48	31.58
4. Lime, phosphorus, potash, and nitrogen	44.3	16.1	14.5	2520	87.39	40.41	8.88	31.53
5. Lime	25.7	10.2	5.4	1424	47.48	---	---	---
6. Lime, phosphorus, phosphorus, and nitrogen	47.1	17.9	15.3	2692	85.91	39.81	8.88	30.93
7. Lime, phosphorus, and potash	47.4	18.2	13.5	2754	84.57	37.97	6.48	31.49
8. Lime and phosphorus	45.5	18.6	12.4	2607	81.88	34.79	5.04	29.75
9. Lime	26.8	10.1	5.8	1399	49.45	---	---	---
10. Lime	27.8	11.0	5.7	1494	46.68	---	---	---
11. No treatment	24.3	10.6	4.7	1320	41.90	---	---	---
12. Phosphorus, potash, and nitrogen	39.8	13.0	12.8	2228	76.10	39.68	8.88	30.80
13. Lime	23.8	9.8	5.1	1348	45.76	33.34	10.50	22.84
14. No treatment	20.5	7.8	3.4	828	35.63	---	---	---
15. Manure	37.1	10.2	6.0	1283	55.86	20.10	5.5 tons	3.64
16. Lime and manure	41.8	12.2	7.5	1605	65.44	19.30	5.8 tons	3.33
17. Lime, manure, and phosphate	51.8	17.7	13.3	2778	94.76	30.13	5.04	25.09

of crop response were started in 1916. Sources of phosphates used were steamed bone meal, basic slag, superphosphate, and rock phosphate. Nitrogen and potash, wherever used, were applied at the rates of 12 pounds and 50 pounds respectively. Limestone was applied, in 1915, at the rate of four tons per acre. Manure, six tons per acre, was applied to the corn crop in the first round of the rotation and after that time in amounts equal to the produce removed except wheat grain.

Results of the experiment are shown in Table XI.

Financial results obtained in Table XI were based upon corn at $0.60 and wheat at $1.25 per bushel; hay at $10.00, and wheat straw at $2.50 per ton. Fertilizer materials were valued as follows: Nitrogen, 20 cents, phosphoric acid, 7 cents, and potash, 6 cents per pound. Rock phosphate was charged at $15.00, and ground limestone at $3.50 per ton.

The conclusion reached as a result of this experiment was that on limed and manured land superphosphate was the most profitable source of phosphorus. The various phosphates produced an average net return per rotation, per acre, as follows: Superphosphate, $13.50; basic slag, $13.13; bone meal, $9.20; and rock phosphate $7.10. On limed land, which has not received manure, superphosphate has been more profitable than rock phosphate.

Rock phosphate has been more profitable than superphosphate when applied to land not receiving applications of either limestone or manure (plots 14 and 15). On land receiving manure

Table XI. AVERAGE YIELDS AND FINANCIAL STATEMENT PER ACRE, PER ROTATION, FROM VARIOUS PHOSPHATE TREATMENTS

Treatment	Lbs. phos. acid per acre	Average acre yields Corn, bu. (1916-1929)	Wheat, bu. (1917-1929)	Hay, lbs. (1918-1929)	Value of three crops in rotation	Value of increase due to fertilizer per rotation	Cost of fertilizer	Net gain due to fertilizer per rotation
0. No treatment	---	23.9	4.4	1276	$29.10	-----	-----	-----
1. Limestone and manure	---	38.3	7.7	1695	44.24	-----	-----	-----
2. Limestone, manure, and bone meal	48	45.7	11.3	2477	57.52	$12.56	$ 3.36	$ 9.20
3. Limestone, manure, and basic slag	48	48.7	12.5	2498	62.16	16.49	3.36	13.13
4. Limestone and manure	---	39.7	8.0	1730	46.39	-----	-----	-----
5. Limestone, manure, and superphosphate	48	50.4	12.8	2599	64.42	16.89	3.36	13.53
6. Limestone, manure, and rock phosphate	192	49.2	11.3	2417	60.57	11.90	4.80	7.10
7. Limestone and manure	---	41.5	9.8	1941	49.81	-----	-----	-----
8. Manure and superphosphate	48	48.3	11.4	2513	60.48	21.81	3.36	18.45
9. Manure and rock phosphate	192	48.9	11.1	2800	61.82	23.29	4.80	18.49
10. Limestone and manure	---	41.4	8.7	1894	49.37	-----	-----	-----
11. Limestone and superphosphate	48	33.2	9.0	2118	45.31	13.33	3.36	19.97
12. Limestone and rock phosphate	192	30.1	7.2	1906	39.83	8.20	4.80	3.40
13. Limestone	---	24.9	5.2	1394	31.27	-----	-----	-----
14. Superphosphate	48	33.9	7.2	1790	41.60	15.45	3.36	12.09
15. Rock phosphate	192	37.3	8.4	2262	47.94	22.15	4.80	17.35
16. Limestone and manure	---	39.4	8.4	1795	47.23	-----	-----	-----
17. Limestone, nitrogen, potash, and superphosphate	48	43.4	10.8	2279	55.65	24.48	8.76	15.72
18. Limestone, nitrogen, potash, and rock phosphate	192	36.2	8.9	2180	47.78	15.63	10.30	5.33
19. Limestone and manure	---	41.2	9.1	1946	50.18	-----	-----	-----
20. Nitrogen, potash, and superphosphate	48	43.0	9.9	2009	52.60	25.27	8.76	16.51
21. Nitrogen, potash, and rock phosphate	192	42.8	9.9	2607	55.71	29.42	10.30	19.12
33. No treatment	---	20.9	4.2	953	25.19	-----	-----	-----

without lime there was very little difference in the profitableness of the two.

PENNSYLVANIA

At the Pennsylvania Station[14] a fertilizer experiment was started in 1881 and continued for a period of 49 years. It was conducted on 144 one-eighth acre plots. A four-year rotation of corn, oats, wheat, and mixed clover and timothy hay was used.

Only twelve of the plots received lime treatments during the first 40 years. Beginning in 1923 lime was added to most of the remaining plots. Lime (two tons per acre) was applied to the corn ground. Fertilizer applications were made to the corn and wheat crops each time they appeared in the rotation.

The soil on which the experiment was made belonged to the Hagerstown silt loam type. It was described as being in a good state of fertility when the plots were laid out.

The object of the experiment was to test the comparative effects of various fertilizer treatments on crop growth. Single ingredients were added to some plots, two ingredients to others, some receiving a complete fertilizer. Prior to

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14. Pennsylvania State College Agricultural Experiment Station Bulletin 264, "50th. Anniversary of the General Fertilizer Tests 1881-1931," 1931, pp. 3-12.

1917, dissolved boneblack was used as the source of phosphorus. Since that time it has been replaced by superphosphate.

Every two years phosphoric acid was applied at the rate 48 pounds per acre; muriate of potash, 100 pounds per acre; and nitrogen (in the forms of dried blood, nitrate of soda, and sulphate of ammonia) at the rates of 24, 48, and 72 pounds per acre.

Results of this experiment show that in every case the yields of the plots were more variable than those receiving phosphoric acid and potash.

In total pounds of crop per acre, neither nitrogen nor potash increased the yields, but phosphoric acid did so quite appreciably. During the first 40 years the total increase, in pounds per rotation, was 18.4 per cent; for 1922-30, without lime, 76.2 per cent; and for 1922-30, with lime, 45.2 per cent.

> Phosphoric acid and potash gave the largest increase over the untreated check plots, nearly as large yields as the nearest complete fertilizer plot. At the price used, the phosphoric acid and potash plots gave a much larger net return than plots receiving, in addition, 24 pounds of nitrogen in dried blood. Then mineral element plots were slightly surpassed in net return by the complete fertilizer plots having 24 pounds of nitrogen in nitrate; but they were superior to sulfate of ammonia plots, except in the 1922 to 1930 period when lime was added.
>
> Used alone, only phosphoric acid has given significant increases. A study of all the figures shows the great importance of phosphoric acid in comparison with nitrogen and potash.[15]

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15. Pennsylvania Bulletin 264., op. cit. p. 12.

A part of the summary of the results of the experiment from 1882 to 1921 is shown in Table XII.

Table XII. AVERAGE ANNUAL YIELDS OF CROPS ON HAGERSTOWN SILT LOAM RECEIVING VARIOUS FERTILIZER TREATMENTS (1882 to 1921)

Treatment	Corn, bu.	Oats, bu.	Wheat, bu.	Hay, lbs.
Nothing	35.7	31.3	12.8	2,335
Nothing	33.7	30.5	12.4	2,189
Dried blood	33.8	30.8	12.4	2,021
Superphosphate	43.6	37.1	15.9	2,899
Muriate of potash	32.7	31.5	11.0	2,068
Dried blood and Superphosphate	46.8	41.1	19.7	3,343
Dried blood and Muriate of potash	34.6	34.3	13.6	2,405
Muriate of potash and superphosphate	52.1	42.3	19.1	3,990
Dried blood, Superphosphate, and Muriate of potash	53.7	44.4	23.6	3,952
Nitrate of soda Superphosphate, and Muriate of potash	57.8	44.5	24.8	4,088
Sulfate of ammonia Superphosphate, and Muriate of potash	49.2	42.6	21.8	3,102
Burnt lime to corn	36.7	30.7	14.2	2,495

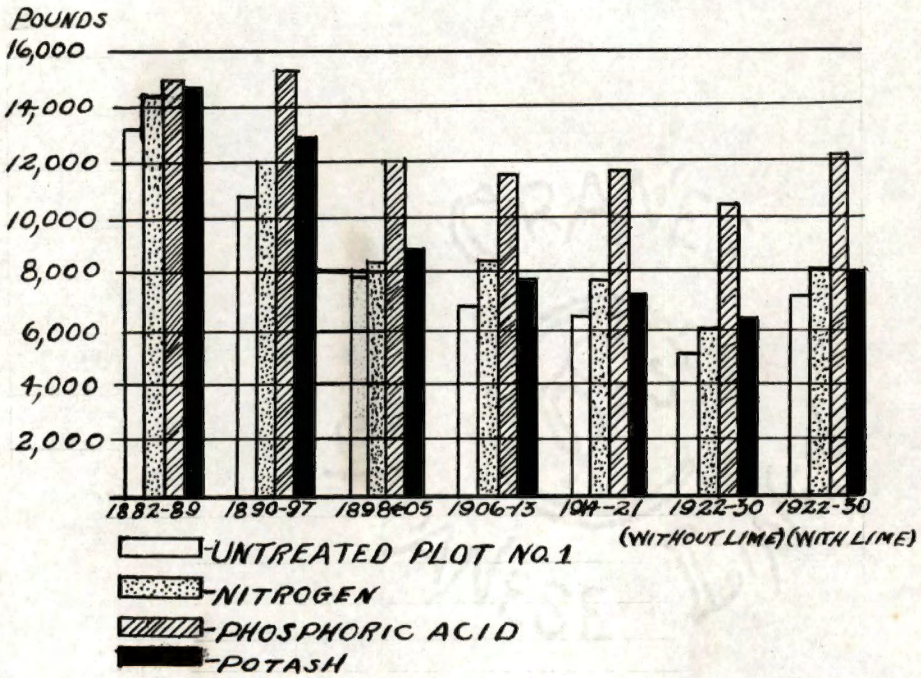


Fig. 1. Yields on plots receiving single fertilizer ingredients, in total pounds per acre, in a rotation at the Pennsylvania Station.

WISCONSIN

Oats.[16]-- Long time field experiments with oats in Wisconsin showed the value of phosphate fertilizer. The soil used belonged to the silt loam and sandy loam classes. The farms on which these trials were made were dairy farms therefore manure was available for use in the rotation.

Acid phosphate was applied broadcast at the rate of 300 pounds per acre.

Results of these experiments, as shown in Table XIII, show an average increase of 12.5 bushels of oats per acre as a result of phosphate fertilizer. At 40 cents per bushel this increase would be worth $5.00. Since the fertilizer used was valued at $3.00 this would leave a net profit of $2.00, providing all the fertilizer charges were made against the oat crop. It was estimated that one-half the phosphate still remained in the soil for the benefit of subsequent crop. Based upon this supposition, the net profit from the fertilizer would be $3.50 per acre.

Corn.--A number of phosphate trials have been made with corn grown on sandy loam, red clay, and silt loam soils in Wisconsin. A summary of the results are shown in Table XIV.

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16. Wisconsin University Agricultural Experiment Station Bulletin 341, "The Use of Fertilizers on Dairy Farms," 1922, pp.11-13.

Table XIII. ACRE YIELDS OF OATS WITH AND WITHOUT PHOSPHATE FERTILIZERS

Kind of soil	Phosphate	No Phosphate
	Bushels	Bushels
Silt loam	87.0	69.5
Silt loam	94.3	64.6
Sandy loam	44.0	38.0
Silt loam	48.9	45.9
Silt loam	50.3	46.8
Silt loam	69.9	50.0
Sandy loam	22.5	17.5
Sandy loam	41.6	26.7
Averages	57.3	44.8

Phosphate added to the crop produced an average of 7.7 bushels of corn per acre more than the check plots. Corn silage was increased, on an average, 3.6 tons per acre by the addition of 300 pounds of acid phosphate.

> At the Ohio Experiment Station the addition of 320 pounds of acid phosphate to manure and lime every three years has given an average annual increase above that receiving manure and lime only, for twenty-one years, of 8 2/3 bushels of corn, 5 1/2 bushels of wheat, and 838 pounds of clover. This increase is worth over $26, while the phosphate cost $4. The director of the Ohio Experiment Station says: "Acid phosphate, either with or without manure, has given large profits in all cases. Per dollar invested, it has been by far the most profitable of all the fertilizer treatments either alone, with lime, or with both lime and manure."[17]

17. Wisconsin Bulletin 341., op. cit. p.12.

Table XIV. EFFECT OF PHOSPHATE FERTILIZERS ON WISCONSIN CORN

Kind of soil	Manure in rotation plus phosphate	Manure in rotation no phosphate
	Bushels	Bushels
Sandy loam	30.0	20.0
Red clay	36.8	30.4
Sandy loam	84.3	71.1
Silt loam	67.9	63.7
Sandy loam	60.2	37.6
Silt loam	46.6	44.6
Silt loam	79.6	75.4
Silt loam	80.0	79.1
Silt loam	90.2	86.3
Average	65.3	57.6
	Corn silage	Corn silage
	Tons	Tons
Silt loam	15.8	8.7
Silt loam	7.8	6.7
Silt loam	14.1	11.7
Average	12.6	9.0

Pasture.[18] -- In many soils phosphorus is the limiting element. One of the best indications of the productivity of a given soil is the amount of available phosphorus it contains. This does not mean that phosphorus is always a perfect indication of the productive ability since other factors also have their influence, but if phosphorus is in abundance the chances are that other factors will be favorable. Studies made by the Wisconsin Station on permanent pasture located on the station farm indicate that there is a close correlation between the amounts of available phosphorus and the total yields per acre.

During the years 1928 and 1929 available phosphate tests were made of the pasture soils. Each time the grass reached a height of four to five inches it was clipped with a lawn mower and a determination of the dry matter content was made. Yields on heavy clay soils which were deficient in available phosphate suffered the most significant decrease.

Soils containing 127 pounds of available phosphorus per acre yielded an average of 4388.5 pounds of dry matter; plots containing 22.5 pounds of available phosphorus yielded 1582 pounds of dry matter.

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18. Wisconsin University Agricultural Experiment Station Bulletin 441, "Permanent Pasture Can Be Improved," 1930, pp. 4-11.

Table XV. RELATION BETWEEN AVAILABLE PHOSPHORUS AND YIELDS OF DRY MATTER TAKEN AT GRAZING STAGES BY LAWN MOWER CLIPPINGS

Pounds available phosphorus per acre	Pounds of dry matter per acre (pasture)
288.0	4710.5
127.5	4388.5
71.0	3358.5
80.5	3133.0
114.5	2881.0
75.5	2469.0
35.0	2399.5
40.0	2199.5
44.0	1591.5
22.5	1582.0
30.0	1576.0

Some plots produced rather low yields even though they were high in phosphorus. It is stated that this was due to shade and lack of moisture. A detailed summary of the relation of available phosphorus and average yields is shown in Table XV.

Not only were the yields greater on soils high in phosphorus, but also there was more crude protein produced. The percentage of crude protein was higher in crops grown

in the presence of abundance of phosphorus. For example, May 29, 24.94 per cent of the dry matter, from fields high in phosphorus, was crude protein; at the same time soil low in phosphorus produced dry matter containing 20.81 per cent crude protein. This difference in percentage is due to the fact that the better soils produce more clover than the poor ones.

Phosphate alone, applied to permanent pastures located at the University Experiment Farm at Madison, failed to give satisfactory increase in yield. Where lime was used with the phosphate an increase of 42.6 per cent was obtained. Potash, phosphorus, and lime used together expanded production 153.2 per cent. Approximately the same results were obtained when phosphorus and potash were added without lime.

Oats, barley, alfalfa, and clover.[19]-- It is stated in Wisconsin Bulletin No. 376 that the thing which will probably do more to increase crop yields over the state as a whole is the use of phosphate fertilizers. A large number of fertilizer trials were made throughout the state and it was found that phosphate fertilizers gave paying results. Results of a number of these experiments are shown in Table XVI.

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19. Wisconsin University Agricultural Experiment Station Bulletin 376, "Profit from Phosphates," 1925, pp. 3-6.

Table XVI. AVERAGE YIELDS PER ACRE IN TRIALS WITH PHOSPHATE FERTILIZER IN WISCONSIN

Crop	No. Trials	Yield with no treatment	Yield with phosphate	Increase
Oats	52	44.6 bu.	53.1 bu.	8.5 bu.
Barley	20	31.0 bu.	35.2 bu.	4.2 bu.
Alfalfa	17	3143 lbs.	3981 lbs.	838 lbs.
Clover	18	3120 lbs.	4061 lbs.	941 lbs.

Phosphate fertilizers, in 52 trials increased the yield of oats, on an average, 8.5 bushels per acre. Alfalfa and clover, first cuttings, were increased 838 and 946 pounds respectively.

At the average Wisconsin price of corn, hay, and small grains it was estimated that $3.50 worth of phosphate would increase crop production $14. In other words, the increase would be worth four times the cost of fertilizer.

It was found that when 400 pounds of superphosphate was applied to a corn crop production was increased, the ears filled out better, and the crop matured one week earlier than corn grown on check plots.

On a farm a few miles south of Madison 400 pounds of 16 per cent acid phosphate per acre increased the yield of oats 15.7 bushels to the acre. The yield of clover, which followed the oat crop, produced 2,932 pounds more cured hay per acre than did the check areas. The soil on which these

crops were grown was described as belonging to the Carrengton silt loam which is one of the best soils in Wisconsin. On the same farm 400 pounds of 16 percent acid phosphate per acre increased the first cuttings of alfalfa 1,033 pounds.

TENNESSEE

Several farms in various Middle Tennessee Counties were selected upon which to run crop and fertilizer experiments.[20] The purpose of these experiments was to determine the supply of the major plant food elements in the various soil types found in that part of the state. In selecting the soils an effort was made to choose those representative of a large area.

The experiments had been in progress two years when this report was made in 1909.

Millet.-- The land upon which millet was grown was mostly old land which had received little attention in the way of manuring and fertilizing. Most of the experiments were located on the Highland Rim. The soils used were of three types: Barrens--gray-colored silt loam; limestone of the Highland Rim---red-colored silt loam; and Cumberland Plateau---sandy loams. An excerpt of the results of these experiments is shown in Table XVII.

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20. Tennessee University Agricultural Experiment Station Bulletin 86, "Experiments With Soils, Fertilizers and Farm Crops," 1909, pp.35; 49-63.

Table XVII. FERTILIZER EXPERIMENTS WITH MILLET GROWN ON MIDDLE TENNESSEE SOILS

Soil type	Locality	Phosphate and potash per acre	Nitrate of soda and yield of hay per acre	
			No nitrate Lbs.	160 lbs. nitrate Lbs.
Barrens, Gray-colored silt loams	Coffee Co.	No treatment	870	2460
		300 lbs. acid phosphate	2270	2964
		150 lbs. acid phosphate and 100 lbs. muriate of potash	1609	4108
	Warren Co.	No treatment	1680	3520
		300 lbs. acid phosphate	3040	4960
		300 lbs. acid phosphate and 100 lbs. muriate of potash	3840	4320
	Putnam Co.	No treatment	3000	----
		300 lbs. acid phosphate	3490	3920
		300 lbs. acid phosphate and 100 lbs. muriate of potash	4280	4720
Limestones of Highland Rim Red-colored silt loams	Overton	No treatment	1640	----
		300 lbs. acid phosphate	3880	6160
		300 lbs. acid phosphate and 100 lbs. muriate of potash	3120	5240
Cumberland Plateau Sandy loams	Cumberland Co.	No treatment	1480	----
		300 lbs. acid phosphate	2200	5320
		300 lbs. acid phosphate and 100 lbs. muriate of potash	1760	5420

Acid phosphate gave good increases in yields whether used alone or with some other fertilizer. The most profitable results were secured whenever it was added at the rates of 150 to 300 pounds per acre rather than a heavy application of 600 pounds.

Chemical analysis of these soils showed them to be decidedly deficient in phosphoric acid.

Nitrate of soda was used at the rates of 40 to 320 pounds per acre. It was concluded that whenever it was used conjunction with acid phosphate or acid phosphate and potash the amount of nitrate could be increased up to 160 pounds per acre.

Corn.-- Fertilizer experiments were conducted with corn similar to those on millet. Phosphate fertilizer was used with and without nitrogen. Combinations of phosphate and potash were also used with and without nitrogen. The phosphate when used alone was applied at the rate of 300 pounds per acre; when used in conjunction with muriate of potash it was applied in quantities of 150,300, and 600 pounds per acre. The phosphate was thoroughly mixed with the soil at the time of planting. Nitrogen was applied as a top dressing.

The experiment was carried out on the farm of Dr. Doyle in Warren County.

An extract of the results published is shown in Table XVIII.

> In this series of experiments phosphoric acid and nitrogen were clearly indicated as the most needed elements of plant food. The most profitable applications per acre, according to the average results, were 300 pounds of acid phosphate together with 160 pounds of nitrate of soda.[21]

Acid phosphate, when used alone at the rate of 300 pounds per acre, increased the production of corn five bushels over the plots receiving no fertilizer. When the same amount was used with 160 pounds of nitrate of soda the increased yield was 17.8 bushels per acre. Plots receiving 300 pounds acid phosphate, 100 pounds muriate of potash, and 160 pounds nitrate of soda per acre produced 39.6 bushels. The same formula containing an additional 300 pounds acid phosphate produced 43.4 bushels per acre. The additional 300 pounds of phosphate was responsible for an increased yield of 2.8 bushels per acre.

A similar experiment with corn grown on the Barrens type of soil on the farm of O. F. Thompson, Warren County, gave profitable results from the use of acid phosphate. No fertilizer gave a yield of 21 bushels per acre. Land receiving 300 pounds acid phosphate yielded 38.2 bushels per acre. This was an increase of 17.2 bushels of corn at a fertilizer cost of $2.55. Six tons of farmyard manure produced an increased yield of 14.7 bushels per acre over the check plots.

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21. Tennessee Bulletin 86., op. cit. p. 53.

Table XVIII. FERTILIZER EXPERIMENTS WITH CORN IN WARREN COUNTY

Treatment	Application of nitrate of soda and yield per acre	
	No nitrate	160 lbs. nitrate
	Bu.	Bu.
No treatment	16.3	28.2
300 lbs. acid phosphate	22.3	36.1
300 lbs acid phosphate and 100 lbs. muriate of potash	19.6	39.6
150 lbs. acid phosphate and 100 lbs. muriate of potash	16.3	23.6
600 lbs. acid phosphate and 100 lbs. muriate of potash	27.9	43.4

The Bulletin states that phosphoric acid and nitrogen are the plant foods most needed in the Barrens type of soil.

Sorghum.-- In Putnam County fertilizer trials showed phosphate to be valuable in the production of sorghum. Plots on which no fertilizer was used produced 1.46 tons of cured substance per acre. Plots on which 300 pounds acid phosphate was applied produced 2.24 tons of cured forage per acre. A complete fertilizer, consisting of 300 pounds acid phosphate, 100 pounds muriate of potash, and 400 pounds of cotton-seed meal per acre, more than doubled the production over plots receiving no treatment.

Cowpeas.[22] -- From fertilizer trials at the Tennessee Experiment Station farm it was concluded that lime was an important factor in securing increased yields from the use of phosphates. Limes plots, to which either acid phosphate or small amounts of Thomas slag and bone meal were added, produced a greener and more abundant growth of cow peas than did unlimed plots. Where lime had been applied and heavy dressings of fertilizers were made, yields of cowpea hay from various phosphate treatments were as follows: Bone meal, 1.43 tons; acid phosphate 1.33 tons; Thomas slag, 1.32 tons; and rock phosphate 1.21 tons, as compared with 1.11 tons per acre for check plots. Of the light application on the limed plots, acid phosphate won first place over bone meal. The cowpeas were turned under each year.

Plots from which the cowpeas were removed each year produced better with rock phosphate than with acid phosphate on the unlimed series; while on the limed series, acid phosphate produced better yields.

Wheat.-- On limed plots, following cowpeas turned under, the various phosphates produced the following increases in yields of wheat over the check plots; Thomas slag, 6.8 bushels; steamed bone meal, 4.7 bushels; acid phosphate, 3 bushels; and rock phosphate, 1.9 bushels per acre.

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22. Tennessee University Agricultural Experiment Station Bulletin 90, "Fertility Experiments in a Rotation of Cowpeas and Wheat, Part 1--The Utilization of Various Phosphates," 1910, pp. 61; 69-70.

The soil on which these experiments were conducted is described as being Cumberland loam. It was well supplied with plant food elements as compared with many of the other soils of Tennessee. It was so much in need of lime that without it alside clover failed on adjoining plots even after the application of 30 tons of farmyard manure per acre. Clover was grown successfully after the application of a ton of burnt lime to the acre.

With only a few exceptions, the phosphates were applied annually.

Irish potatoes.[23] -- Experiments conducted on the Cumberland Plateau, near Crossville show phosphate fertilizer to be important in the production of Irish potatoes. Trials were made on six different farms chiefly to compare the yeilds made with manure and those made with manure reinforced with fertilizers.

Of the six trials, 12 tons of manure per acre gave an average increase of 92 bushels of salable potatoes over the check plots. An average of five trials with 12 tons manure and 600 pounds acid phosphate gave an increase of 138 bushels of salable potatoes per acre. From this it may be concluded that the phosphate was responsible for the additional 46 bushels.

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23. Tennessee University Agricultural Experiment Station Bulletin 101, " A Rational Improvement of Cumberland Plateau Soils, Conclusions from Six Years of Field Experiments with Various Farm Crops," 1913 pp. 115-118.

Without fertilizer or manure, one series produced 24 bushels per acre, only four bushels of which were salable. On the same series 12 tons of farmyard manure raised the production to 196 bushels per acre, 140 bushels of which were salable. An application of 600 pounds of acid phosphate per acre increased the yield to 248 bushels, 208 bushels of which were salable.

Phosphate in addition to manure affected an increase in all series as may be seen by refering to Table XIX.

When 320 pounds of nitrate of soda was added to the manure and phosphate a further increase of 20 bushels of salable potatoes per acre was made.

Tobacco.[24]-- In 1913 fertilizer experiments were started with tobacco on a farm near Clarksville. The soil was described as being a typical tobacco soil of that section. It was a poor gray-colored silt loam belonging to the Clarksville stony loam type. A chemical analysis, strong hydrochloric acid being used as a solvent, of a similar soil from a near by farm revealed a phosphoric acid content of only .05 per cent which is very poor.

Acid phosphate was applied at the rates of 100, 200, 300, and 400 pounds per acre along with nitrogen and potash.

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24. Tennessee University Agricultural Experiment Station Bulletin 129, "Dark Tobacco Fertility Experiments at the Clarksville Station--Results from a Ten-Year Perios--1913-1922," 1924, pp. 3 & 12.

Table XIX. FERTILIZER EXPERIMENTS WITH IRISH POTATOES ON THE CUMBERLAND PLATEAU--YIELDS PER ACRE

Series	No Fertilizer		Manure, 12 tons		Manure, 12 tons; acid phosphate 600 lbs.	
	Total bu.	Salable bu.	Total bu.	Salable bu.	Total bu.	Salable bu.
1	50	45	153	126	212	179
2	42	22	195	150	---	---
3	24	4	196	140	248	208
4	32	20	128	116	209	201
5	110	90	212	193	237	213
6	83	62	109	76	139	111

It was concluded at the end of three years that a large part of the increased yields was due to acid phosphate. The most profitable application seemed to be 300 pounds per acre. The increased value of 400 pounds per acre over 300 pounds seemed doubtful.

Lespedeza[25]-- At the West Tennessee Experiment Station a three year fertilizer test on lespedeza was made on a thin gray soil. One thousand pounds of acid phosphate was applied per acre. Some of the plots were limed with ground limestone

25. Tennessee University Agricultural Experiment Station Bulletin 123, "Lespedeza," 1921, p. 14.

at the rate of two tons per acre.

It was concluded from this experiment, and others conducted on the same farm, that phosphate was not profitable for lespedeza on this particular soil.

In other experiments,[26] conducted at the West Tennessee Station on corn, cowpeas, clover, wheat, cotton, and alfalfa, it was found that only the last two named profited any from the application of 200 pounds of acid phosphate per acre.

NEW HAMPSHIRE

Alfalfa.--In 1926 the New Hampshire Experiment Station[27] started a series of fertilizer experiments on alfalfa. The trials were carried out on a farm in Greenland. Prior to the seeding of the alfalfa crop a basic treatment of two tons of ground limestone and 20 tons of manure per acre was made.

Since the experiment was started, superphosphate had been added at the rate of 500 pounds per acre each year, with the exception of 1927. It was used alone on some plots and in combination with other plant food elements on others. Check plots received the basic treatment in 1926; but since that time no additional treatments have been made.

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26. Tennessee University Agricultural Experiment Station Bulletin 109, "Fertility and Crop Experiments at the West Tennessee Station," 1914, p. 216.

27. New Hampshire Agricultural Experiment Station Bulletin 271, "Fertilizer Experiments on 'Run-Out' Hay Land," 1933, pp. 3-7.

A chemical analysis of the soil upon which the alfalfa was grown showed that the top soil alone contained 1,800 of phosphorus.

At the end of the experiment in 1931, it was concluded that superphosphate, when used alone, had not given paying results. The response was somewhat better when this compound was used in conjunction with lime or manure, or lime and manure, than when used alone.

When potash was used with the superphosphate yields were increased materially. Credit for this increase was given to the potash instead of to the superphosphate.

This Station does not recommend superphosphate as a top-dressing for alfalfa. It is stated that when it is applied in this manner the phosphorus is quickly absorbed or fixed in the first inch or two of the top soil. Since alfalfa is a deep rooted crop, only a few of the feeding roots being in the upper portion of the soil, the full effect of the superphosphate is not obtained by the plants.

Tomatoes.[28]--In 1920 a fertilizer experiment was carried out at Durham with tomato plants. The land on which the tests were made was described as being a rather poorly drained, medium dark brown loam. All plots, except those used as checks, were treated with 500 pounds acid phosphate per acre; others with 1000 pounds of phosphate; and still others with 1500 pounds of phosphate.

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28. New Hampshire Agricultural Experiment Station Bulletin 28, "Effect of Phosphorus Upon the Yield and Time of Maturity of the Tomato," 1925, pp. 10-13.

Data from this experiment showed that acid phosphate, when used in addition to manure, produced marked results. The amount of early fruit, the total yield, the average number of blossom clusters per plant, the average number of blossoms per plant, and the average number of blossoms per cluster were increased by the phosphate.

The results obtained from the different rates of phosphate applications were so variable that a comparison of the effectiveness of each application was difficult. However, 1000 pounds of acid phosphate per acre seemed to be the most effective. No explanation was offered for this.

Yields of the check plots were much less than those of the treated plots.

MONTANA

Between 1928 and 1935 a large number of phosphate trials, with crops, were conducted in various parts of Montana.[29] Soil samples were taken from representative farms in nine different counties. These were tested in the laboratory, by the Winogradsky method, to determine the phosphorus deficiency. Out of 53 samples, 51 showed an extreme deficiency; the remaining two were moderately deficient in phosphorus.

One hundred eighteen tests were made on 55 representative farms the purpose of which was to determine crop response to phosphate fertilizers applied to these soils.

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29. Montana State College Agricultural Experiment Station Bulletin 316, "Report on the Investigation of Phosphorus--Deficient Soils, 1935," 1936, pp. 3-17.

Treble superphosphate and ammoniated phosphate were used as the sources of plant food.

Alfalfa.--Treble superphosphate was applied to the alfalfa field in the spring of 1935, by means of a grain drill, at the rate of 125 pounds per acre.

The first cutting showed some response to the fertilizer treatment, but was not as significant as that obtained from the second cutting. Some comparisons were not significant because of dry weather during the summer of 1935. Out of a total of 54 fields, 20 gave an increased yield of more than 500 pounds per acre per cutting. Nine of these 20 gave an increased yield of more than 1,000 pounds of hay per acre each cutting. The largest increase was a total of 3,642 pounds of hay from both cuttings.

From observations of other alfalfa fields which had received 125 pounds of treble superphosphate per acre in 1933, it was concluded that the fertilizer was still giving good results three years after its application.

Wheat.--Treble superphosphate gave better results than ammoniated phosphate when applied to spring wheat. The former material increased the yield from 34.6 to 43.2 bushels per acre; this was one bushel more than the increase produced by the latter. Winter wheat produced 49.6 bushels per acre on land receiving treble superphosphate. This was an increase of 24.2 bushels over the check plots. In all cases the fertilizer materials were applied at the rate of 125 pounds per acre.

Oats.--The oat yield was 118.5 bushels per acre on plots receiving 125 pounds of treble superphosphate per acre as compared with 69.5 bushels per acre on check plots. The same amount of ammoniated phosphate produced 56.2 bushels of grain per acre as compared with 50 bushels on unfertilized plots.

Barley.--Ammoniated phosphate increased the yield of barley 11.3 bushels per acre which was .7 bushels more than that produced by plots treated with treble superphosphate.

Canning peas.--On six out of eight plots, 125 pounds of phosphate per acre increased the percentage of grade "A" peas; the yield was increased on five of the plots. With one exception, the value per acre was increased by the addition of phosphate. Expressed in terms of the Montana market price, in 1935, $3.15 worth of fertilizer produced an average increased income of $10.14 per acre.

Mustard.--Phosphate fertilizer trials with mustard were made on seven farms. Six of these fields were dry land, and due to the dry season in 1935, moisture seemed to be the limiting factor. On these dry fields fertilizer did not show any noticeable results. The irrigated field showed some response, but it was only enough to pay for the fertilizer treatment.

Irish potatoes.--Treble superphosphate and ammoniated phosphate trials on potatoes in seven Montana counties gave favorable results in 1935. In practically all of the plots phosphate fertilizer increased the vine growth, the number of tubers set, the yield, and hastened the maturity. The

grade of the tubers was considerably strengthened. Phosphorus had a tendency to reduce the lenght of the tuber in proportion to its width. Treble superphosphate had no marked influence on the size of the tuber; a slight increase was produced by the ammoniated phosphate.

Sugar beets.[30]--In a few areas of Montana, where the soil was very deficient in phosphorus, the addition of this element has produced increased yields up to 15 tons per acre. The Station considered an increase of three tons per acre as being the average for the use of 150 pounds of phosphate fertilizer. It is stated that one ton of beets will pay for the cost of the fertilizer material.

Chemical analyses have failed to show that phosphate fertilizer made any change in the percentage of sugar which the beets contained. The enhanced yields do increase, however, the total amount of sugar that may be produced by an acre.

FLORIDA

Hairy vetch and Austrian peas.[31]--At the Florida Station hairy vetch and Austrian peas were grown on plots which had received applications of superphosphate at the rates of 400 and 800 pounds per acre. On adjacent plots, the same crops

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30. Montana State College Agricultural Experiment Station Circular 148, "A Review of the Experimental Work with Phosphate in Montana---1928-1935," 1936, pp. 2-3.

31. Florida University Agricultural Experiment Station "Annual Report for the Fisical Year Ending June 30, 1932," pp. 36 & 46.

were grown without fertilizer. It is stated that the yields, in all cases, of the plots receiving superphosphate were more than double the corresponding check plots. There was no noteworthy difference in the yields of plots treated with 400 pounds and those treated with 800 pounds of superphosphate.

In other experiments carried on by the Station with the same crops, superphosphate was applied at the rates of 300 pounds and 600 pounds per acre. Three hundred pounds per acre seemed to produce as much crop growth as did 600 pounds per acre.

GEORGIA

Sweet potatoes.[32]--Fertilizer experiments covering a five year period, were conducted at the Georgia Station on sweet potatoes. The object of these tests was to determine the influence of a single fertilizer element upon the yield, texture, keeping quality, and color of the sweet potato. Twenty-one hundred pounds of 16 percent phosphate was used per acre.

The potato crop varied so much from year to year that it was difficult to make comparisons of the fertilized and check plots. It was concluded that phosphate had little influence upon the yield, or keeping quality. Phosphate did, however, produce potatoes that were more uniform in size and somewhat better in texture.

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32. Georgia Experiment Station Bulletin 107, "Sweet Potatoes--Culture, Storing and Studies in Fertilizing," 1914 pp. 100-108.

Cotton.[33]--A comparison of the different forms of phosphate available to Georgia farmers was made from 1919 through 1925. Kinds of fertilizers used were: Superphosphate, Florida pebble rock phosphate, Tennessee brown rock phosphate, Tennessee blue rock phosphate, and Florida soft rock phosphate. Each material was applied to cotton plots at the rate of 400 pounds per acre.

Prior to 1919 the soil upon which this experiment was conducted had been well supplied with phosphate. For this reason, little difference was noted in the crop during the first two years.

During the last four years, superphosphate produced the largest yields. The average for the superphosphate plots for four years was 635 pounds of seed cotton per acre as compared with 573 pounds for the rock phosphate and 512 pounds for the no phosphate plots. There was little difference in the yields produced by the various rock phosphates.

MICHIGAN

Potatoes.[34]--The value of phosphate fertilizer to potatoes grown on the sandy soils of Michigan has been shown by a number of field experiments. Three hundred pounds of 16 per cent acid

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33. Georgia Experiment Station Bulletin 152, "Cotton Fertilizers and Cultural Methods," 1929, pp. 16-

34. Michigan Agricultural College Experiment Station Bulletin 284, "Some Information and Suggestions Concerning the Use of Phosphorus," 1919, p. 28.

phosphate per acre produced 132 bushels of potatoes. The corresponding check field received no fertilizer and yielded 100 bushels to the acre.

MISSISSIPPI

Alfalfa.[35]--From 1926 through 1929 fertilizer experiments, with alfalfa, were conducted in Mississippi by the United States Department of Agriculture in cooperation with the Mississippi Agricultural College and Experiment Station. The following kinds, and rates per acre, of phosphate were used: Superphosphate, 250 and 500 pounds; and basic slag, 1000 pounds. Manure, when used, consisted of ten and twenty ton applications.

The no-fertilizer plots produced an average annual yield of 1.3 tons of alfalfa hay during the four years. The plots receiving 500 pounds of superphosphate per acre produced an average of 2.2 tons which was only 0.2 tons more than that produced by 250 pounds of superphosphate. Twenty tons stable manure increased the yield to 3.22 tons per acre. There was practically no difference between the yields from the two forms of phosphate.

Two hundred fifty pounds of superphosphate, added to an acre of the alfalfa crop, increased the yield of the subsequent corn crop from 29.98 bushels to 38.07 bushels per acre. This is an increase of 8.09 bushels from the fertilizer

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35. U. S. D. A. Technical Bulletin 419, "Forage-Crop Field Experiments at West Point, Miss.," 1934, pp. 7&8.

residue.

IOWA

Twelve cooperative field experiment, with fertilizers, were conducted in Iowa[36] over a period of 10 years. The soil on which the trials were made belonged to the Carrington loam type.

Treatments were as follows:

1. Check
2. Manure, eight tons per acre once in four years.
3. Manure, eight tons per acre once in four years; and enough lime to neutralize the soil acidity.
4. Manure, eight tons; lime; and rock phosphate, one ton per acre once in four years from 1918 to 1925, and 1,000 pounds once in four years thereafter.
5. Manure, eight tons; lime; and 200 pounds 16 per cent superphosphate per acre annually until 1923, thereafter 150 pounds per acre three out of four years.
6. Manure; lime; and 300 pounds per acre annually of 2-8-2 fertilizer until 1922, thereafter 200 pounds of 2-12-2 three out of four years.

Corn.--The check plots produced an average of 45.5 bushels of corn per acre. Manure, alone, increased the yield 8.2 bushels. Lime, in addition to manure, raised the production

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35. Iowa State College Agricultural Experiment Station Bulletin 276, "A Soil Management Program for Carrington Loam," 1931, pp. 70-74.

2.8 bushels per acre. Rock phosphate and superphosphate yielded an additional gain of 1.9 and 3.8 bushels per acre respectively. Superphosphate produced 0.8 bushel more corn per acre than did the complete fertilizer.

Oats.--Superphosphate, when used with lime and manure, produced 7.7 bushels oats per acre more than did the plots which received applications of lime and manure alone.

Clover and timothy, sweet clover, alfalfa, and winter wheat.--All of these crops were benefited by the use of phosphate fertilizers. Superphosphate showed better results than rock phosphate on all crops except sweet clover. In most cases the difference was small.

ALABAMA

Vetch.[36]--By a series of experiments conducted by the Alabama Station, on three farms, the value of phosphate in producing vetch was shown. The trials covered the period from 1927 through 1935 during which time 23 crops were produced. Phosphated plots were fertilized with 400 pounds of superphosphate per acre.

At the Andalusia field, plots treated with superphosphate averaged 8,092 pounds of vetch per acre, annually, over a period of seven years, while those receiving no fertilizer produced only 2,734 pounds.

An average of 23 crops was: for phosphated areas,

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36. Alabama Polytechnic Institute Agricultural Experiment Station Circular 74, "Hairy Vetch and Austrian Winter Peas for Soil Improvement," 1936, pp. 6-7.

5,923 pounds per acre; and for check areas, 1,473 pounds of vetch per acre. These figures show that without phosphate fertilizer the yield of vetch was very small.

Cotton.[37]--Two hundred twenty-six fertilizer experiments with cotton were conducted on seven soil types in Alabama. Some plots were treated with 240 pounds superphosphate per acre; others, with cotton seed meal; and still others with a complete fertilizer. In every instance phosphate increased the yields of cotton over the corresponding check plots. This increase ranged from 69 to 170 pounds of seed cotton per acre. The complete fertilizer proved to be the most profitable treatment.

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37. Alabama Polytechnic Institute Agricultural Experiment Station Bulletin 219, "Fertilizer Experiments With Cotton," 1923, pp. 5-21.

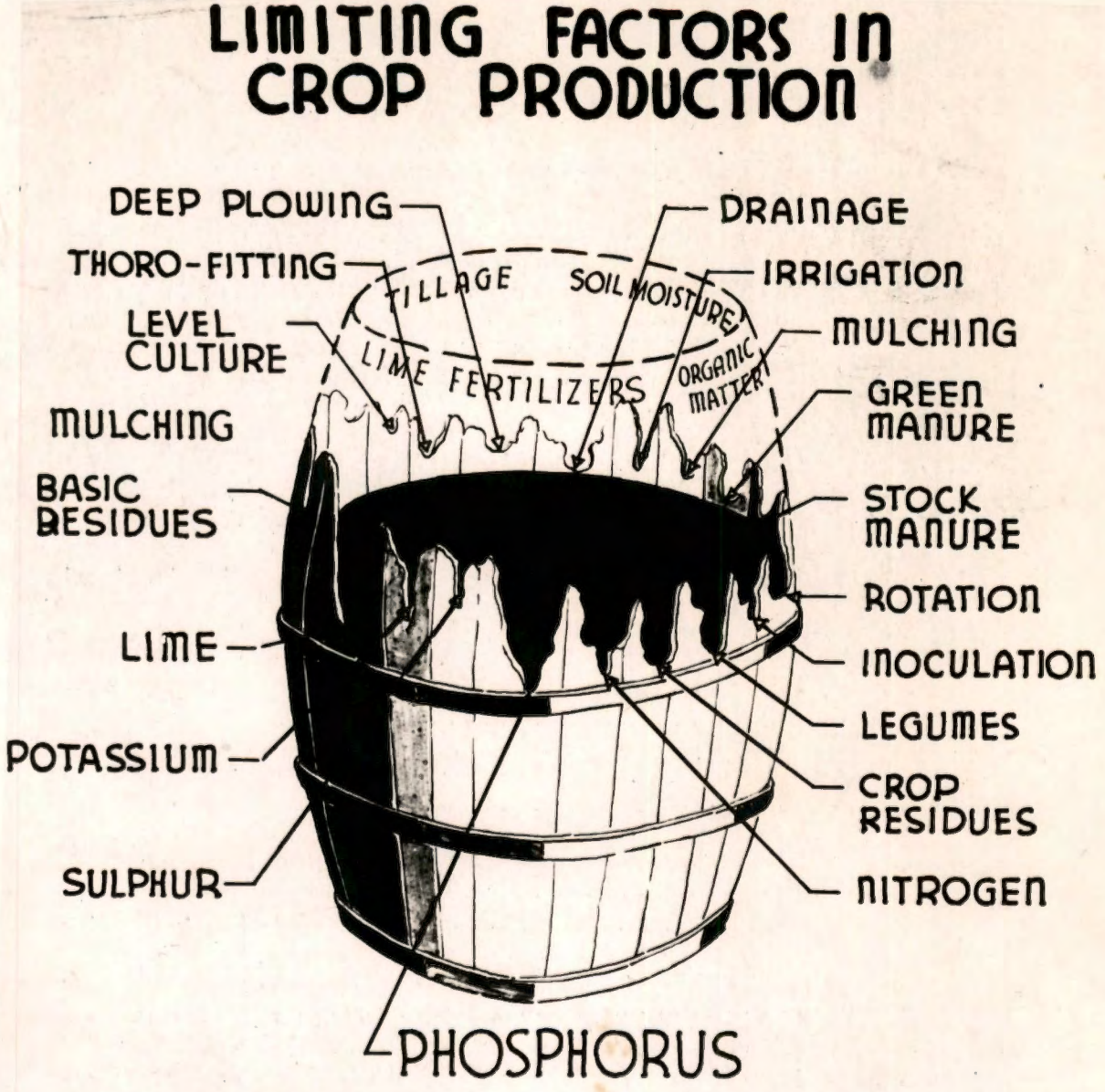


Fig. 2. THIS DIAGRAM SUGGESTS THE VARIOUS FACTORS MOST FREQUENTLY FOUND TO BE THE CAUSE OF LOW CROP YIELDS AND POOR PLANT COVER — PHOSPHORUS IS THE MOST CRITICAL AND HENCE THE LIMITING FACTOR

* Submitted by E. C. Pippin, Agricultural Adviser, Tennessee Valley Authority.

EFFECT OF PHOSPHORUS ON PLANT DEVELOPMENT

Van Slyke[38] states that a soil well supplied with available phosphorus is conducive to rapid development of young seeding. The reason for this is that phosphorus is an important element in the development of the root system. If an abundant supply of available phosphorus is present root growth is stimulated consequently the feeding power of the young plant is increased.

Phosphate also tends to hasten the maturity of a crop. Van Slyke[39] further states that it has been shown that, under favorable conditions, there may be as much as a week's difference in the ripening period of a crop due to the supply of available phosphorus.

The effect of phosphorus on the relative production of grain and straw is marked.[40] The ratio of grain to straw is narrowed in the presence of an abundance of this element. As has been shown elsewhere in this thesis, it is often a limiting factor in the production of grain crops.

Hall[41] has shown, from experiments with wheat at Rothamsted, that the percentage of nitrogen in grain is higher when grown on land low in phosphorus than when grown in the presence of an abundant supply of this element.

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38. Van Slyke, L.L., Fertilizers and Crop Production, p.52.
39. Ibid., p. 52.
40. Ibid., p. 53
41. Hall, A. D., Fertilizers and Manures, pp. 152-154.

DIAGNOSING PHOSPHORUS DEFICIENCIES OF A SOIL

Bear[42] gives some simple suggested principles which may be used in diagnosing phosphorus deficiencies of a particular soil. It should be understood that these are by no means perfect, but by following these principles a farmer can often determine something of the phosphate needs of his soil.

By an examination of the soil phosphorus deficiencies are indicated if it is: (1) heavy in texture, (2) low in humus, (3) strongly acid, and (4) poorly drained.

Plant observation will indicate a lack of phosphorus if: (1) the plants are stunted and leaves are pale green, (2) low yields of legumes are produced, (3) the leaves of tomatoes have a purple color, and (4) cereal crops are slow to mature and produce low yields of grain.

By knowing something of the previous management of the soil one can often determine, to some extent, the need for phosphorus fertilization. From a managerial point of view deficiencies are indicated: (1) if livestock farming has been followed, (2) if legume crops have been grown continuously or frequently, and (3) if continuous or frequent production of cereal crops has been followed.

There are a number of quick tests on the market, and still others worked out by Agricultural Experiment Stations, which may be used in determining the available phosphoric acid.

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42. Bear, F. E., Theory and Pritice in the Use of Fertilizers, pp. 262-268.

OBJECT OF THE EXPERIMENT

The experiment was designed to test the response of the major cultivated soil types found in Putnam County to phosphate fertilizer, Marglobe tomato plants being used as the medium, with the following treatments:

1. Nitrogen and potash with no phosphate
2. Nitrogen and potash with phosphate
3. Nitrogen and potash with differenct amounts of phosphate



Fig. 3. University of Tennessee greenhouse

LOCATION OF EXPERIMENT

This experiment was carried out in the greenhouse located south of Morgan Hall on the University of Tennessee farm. Pots, in which the plants were grown, were set on a soil table in the west part of the east section of the house.

There was a line of ventilators along each side of the ridge and along the two exterior walls. Heat was provided by means of steam coils located under the soil tables. The particular table upon which this experiment was carried out was well exposed to sunlight until late afternoon when an interposition was made by another part of the house.

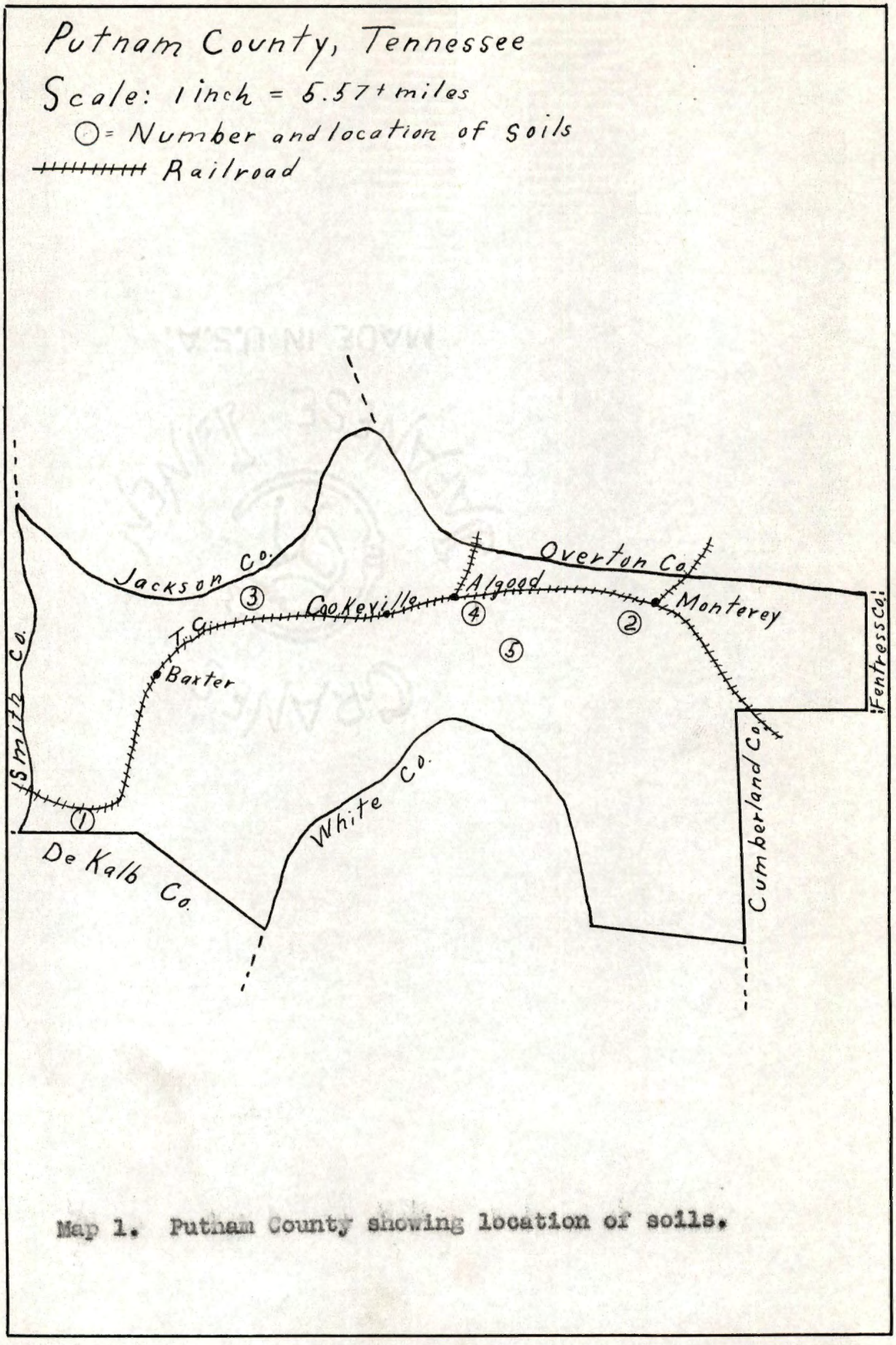
METHODS EMPLOYED IN THE EXPERIMENT

Five soil samples were collected from various parts of Putnam County December 31, 1937. Three of these came from farms in the Highland Rim, one from the Cumberland Plateau, and one from the Central Basin. An effort was made to secure samples which were comparable to the soils in a large agricultural area. All of the major soil types in the County were represented in this collection.

The slope of each field was determined, by means of a level, at the time of the sampling. A history of the soil was secured from occupants of each farm. Also, the farmer was asked for an estimate of the number of bushels of corn his field would yield per acre, under favorable weather conditions, without fertilizer.

Location of these farms is shown on Map 1.

Most crop plants feed within the upper six inches of the soil; therefore the sampling for this experiment was limited to the top six inches.



Map 1. Putnam County showing location of soils.

Each soil was steamed under nine pounds of presure for approximately two hours. The purpose of this was to destroy any plant disease that might have been present.

After the steam treatment, the soils were allowed to dry thoroughly. Each was ground and then sifted through a one-fourth inch mesh screen. This was done in order to produce a uniform mixture, and to remove any gravels that might interfer with plant growth.

The pulvarized soils were placed in glazed pots which were approximately 6½ inches deep and 6½ inches in diameter. Three-quarter inch holes were made in the bottom of each to provide for aeration. Seven pounds of soil was used in each pot which filled the containers within 1.5 inches of the top.

The soils were numbered 1,2,3, etc. Each soil was arranged in a series of five pots designated as 1A, 1B, 1C, etc. This made a total of 25 pots, there being five A's, five B's, five C's, five D's, and five E's.

Fertilizer treatments.--The soil in an acre of land six inches deep weighs, on an average, 2,000,000 pounds. Since the soil being used in this experiment was taken from the top six inches, the above weight was used in calculating the amounts of fertilizers to apply to each pot, on an acre basis.

Both muriate of potash and nitrate of soda were applied to all pots in each soil series at the rate of 100 pounds and 200 pounds per acre respectively. These were applied as a side dressing one week after the plants were transplanted.

Calcium metaphosphate (65% P_2O_5) was used as the source of phosphorus. Each soil was treated with the same amount of this material. Series treatments were as follows:

Series	Lbs. metaphosphate per acre
A	None
B	50
C	100
D	200
E	400

All of the phosphate was applied at the time of transplanting.

The tomato plants, which had been grown in flats in the greenhouse, were transplanted January 27. At this time they were four weeks old and were approximately 2.5 inches in height. In order to avoid root injury, about one cubic inch of soil was removed with each plant. A cone-shaped depression, in which the plant was to be set, was made in the soil of each pot. The metaphosphate was mixed with a small portion of soil in this depression in order that the plants might be stimulated by the fertilizer early in their stage of development.

On March 8 another application of nitrate of soda was made to plants 1C, 2C, 3C, and 4C at the rate of 200 pounds per acre.

Watering.--Hand watering was practiced throughout the experiment. At first the plants were watered by pouring it on the soil. Due to the puddling effect this method was discontinued early in the experiment. The later method used was to place the pots in glass dishes filled with water to a depth of about

two inches. This allowed moisture to pass up through the soil by capillary attraction, thus avoiding the puddling effect.

During the early period of the experiment watering was required only about once each week, but as the plants grew this period was gradually narrowed until additional water was needed every third day.

THE SOILS

Each of the soils was tested in the laboratory for available nitrogen and phosphorus by the "Cunninghamella Plaque Method." This method was developed of A. Mehlick, E. B. Fred, and E. Truog.[43&44]

The available potash was measured by the "Aspergillus Niger Method." Experiments with this method were carried on by A. Mehlich, E. B. Fred, and E. Truog.[45]

The "Truog Reaction Test" was used to determine the pH value.

The results of these tests are shown in Table XX, XXI, XXII, and XXIII.

Soil No. 1.--This soil was taken from the Central Basin

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43. Mehlich, A., Fred, E. B., and Truog, E., "The Cunninghamella Plaque Method of Measuring Available Phosphorus in Soil," Soil Science, Volume 38, pp. 445-458, 1934.

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and belonged to the gravelly loam series. It was largely an alluvial soil having been washed from nearby hills. Laboratory tests for available plant food showed it to contain 130 pounds nitrate nitrogen (NO_2), 125 pounds phosphoric acid (P_2O_5), and 182 pounds of potash (K_2O). The field had a slope of 3.25%.

Table XX. RESULTS OF THE CUNNINGHAMELLA PLAQUE TEST FOR AVAILABLE NITRATE IN SOIL

Soil No.	Diameter of fungus growth in mm. Check	Check	Response	Response	Lbs. NO_2 per acre
1	24	28	48	40	130
2	26	32	45	46	145
3	43	45	56	56	220
4	20	22	35	35	110
5	24	25	29	28	122

Table XXI. RESULTS OF THE CUNNINGHAMELLA PLAQUE TEST FOR AVAILABLE PHOSPHORUS IN SOIL

Soil No.	Diameter of fungus growth in mm. Check	Check	Response	Response	Lbs. P_2O_5 per acre
1	25	25	38	35	125
2	8	9	34	32	43
3	10	10	39	39	50
4	11	11	22	22	55
5	8	8	20	20	40

Table XXII. RESULTS OF THE ASPERGILLUS NIGER TEST FOR AVAILABLE POTASSIUM IN SOIL

Soil No.	Weight of mycelium in mg. Check	Check	Response	Response	Lbs. K_2O per acre
1	.437	.460	1.260	1.355	182
2	.568	.528	.880	.868	220
3	.360	.387	1.300	1.363	142
4	.414	.423	1.237	1.291	170
5	.465	.480	.808	.825	190

Table XXIII. RESULTS OF TRUOG REACTION TEST

Soil No	pH value
1	5.8
2	5.3
3	4.5
4	6.0
5	6.3

Approximately 40 years ago this field was cleared. Since that time it has been under cultivation every year. A definite rotation has been used as follows: Corn, oats, and red clover and timothy three years. The only organic matter that has been incorporated consisted of the clover and timothy sod. Once

in each seven years, on an average, 10 tons of manure per acre has been applied to the field. No commercial fertilizer had been used. It was estimated that this soil would produce 40 bushels of corn per acre with no fertilizer treatment.

Soil No. 2.--This soil belonged to the DeKalb series of the Cumberland Plateau. It contained 220 pounds of available potash, 145 pounds nitrogen, and 43 pounds of phosphoric acid per acre.

The slope of this field was 8.67%. The soil has been under cultivation for about 40 years. No definite rotation has been followed. Green manure and cover crops have not been used which probably explains the reason for the organic content being so low. Corn, millet, and sorghum constituted the crops usually grown. Occasionally 100 pounds of 16% superphosphate was applied to the corn crop. Without fertilizer, the owner estimated that the field would produce five to seven bushels of corn per acre.

Soil No. 3.--This sample came from a field with a slope of 5.16% located on the Highland Rim. It belonged to the "Barrens" type. Its available plant food content was: 220 pounds nitrogen, 50 pounds phosphoric acid, and 142 pounds potash per acre. The organic content was low which made the soil to puddle.

No definite rotation has been followed during the 35 to 40 years it has been under cultivation. Wheat, oats, rye and red-top have been grown to some extent, but the usual

crop has been corn. The only thing that has ever been done toward maintaining the fertility of the soil was to apply 100 pounds of 16% superphosphate per acre to the corn crops. An estimated 10 bushels of corn per acre could be grown without fertilizer.

Soil No. 4.--This soil belonged to the red-colored soils of the Highland Rim. Its available plant food content, as revealed by laboratory tests, was as follows: Nitrogen, 110 pounds; phosphoric acid, 55 pounds; and potash, 170 pounds per acre.

The usual crops grown on this farm consisted of corn, oats, and soy beans; but no systematic rotation has been followed. Nothing has been done to improve the soil, and fertilizer has not been used during the past 10 years. This field produces about 15 bushels of corn per acre. Due largely to the management of this land, and to the 10% slope, sheet erosion has removed much of the top soil.

Soil No. 5.--This soil was taken from the Highland Rim and belonged to the red-colored type of that area. The dark brown color indicated that it was well supplied with organic matter. Laboratory tests for available plant food showed it to contain 122 pounds of nitrogen, 40 pounds of phosphoric acid, and 190 pounds of potash per acre.

Although the slope of the field was 27% there were little indications of erosion. For approximately 40 years corn was grown on this soil each year. Fertilizers and manures were never used.

About 10 years ago blue grass was sown in the field, and it has been used as a permanent pasture since that time.

DISCUSSION OF RESULTS

Soil 1 was badly infested with tomato wilt. Plants 1A, 1C, and 1E died with this disease within two weeks after plants were transplanted. Other plants were set in the same pots. The second plants in 1A and 1E died. These were again replaced. Finally all of the plants took the disease and it gradually spread over each plant until all died. For this reason growth comparisons in this soil are difficult.

Growth of Plants

After the plants recovered from the transplanting there was a marked difference in the rate of growth of the A series as can be seen in Fig. 4 . Plant 5A showed the most abundant growth with 4A a close second. Even these grew slowly and showed a purple color on the bottom side of the leaves. Plants 2A and 3A grew very little during the first 42 days. There was a pronounced purple color on the leaves of these plants.

During the latter part of the experiment 5A increased in growth until it attained a height of 24 inches May 2. Other plants in this series grew very little during this time. The increase in height of 2A was 3.5 inches during the 93 days that the experiment was conducted.

From the outset of the experiment plants which had received metaphosphate treatments grew rapidly. These plants,

which included the B, C, D, and E series, were on an average more than two times as tall as the A series at the end of 42 days. The leaves of the plants which had been treated with phosphate had a yellow color with the exception of those in soil number 5. Plants 1C, 2C, 3C, and 4C were side dressed with 200 pounds of nitrate of soda per acre. This failed to produce any response in either color or growth.

Toward the end of the experiment, which was concluded May 2, the lower leaves on all of the plants which had been treated with phosphate fired and dropped off. No difference was noted between the different rates of phosphate applications.

Growth measurements are shown in Table XXIV. Figures 4, 5, 6, 7, 8, 9, and 10 show each of the plants and also comparisons.

No appreciable difference in growth was noted between the various rates of phosphate application.

Blossoms

In Table XXV is shown the date that the first blossom appeared on each plant. There is a close correlation between the growth of plants and the earliness of the first blossom; the best plants blossomed first. Phosphate fertilizer aided materially in producing early blossoms, but the rate at which it was applied seemed insignificant. Also, the best plants produced the largest number of blossoms. Only one of the plants which was not treated with phosphate bloomed.

Fruit

In the absence of phosphate fertilizer no fruit was set. The better plants set the largest number of fruit.

Since the number of tomatoes produced was so small it was difficult to make significant comparisons between the different rates of phosphate applications.

Roots

Figure 11 shows the root development of each plant. Phosphate fertilizer exerted a positive influence upon the production of roots. The amount of root growth corresponded closely to the amount of stem and leaf growth.

Table XXIV. HEIGHT OF TOMATO PLANTS IN INCHES, 42 AND 93 DAYS AFTER TRANSPLANTING

Date	Soil No.	A	B	C	D	E
March 12	1	9	14	14	15	12
May 2	1	17	46	39	46	20*
March 12	2	4	14	12	13	13
May 2	2	6	27	28	29	31
March 12	3	6	15	14	16	16
May 2	3	9	42	36	34	44
March 12	4	7	17	18	16	16
May 2	4	14	37	43	36	38
March 12	5	7	13	16	16	16
May 2	5	24	37	36	43	36

* Top died from tomato wilt.

Table XXV. DATE OF FIRST BLOSSOM

Soil No	A	B	C	D	E
1		April 6		April 2	
2		March 24	April 1	March 22	March 24
3		March 20	March 21	March 20	March 20
4		March 19	March 20	March 21	March 19
5	April 18	March 19	March 12	March 14	March 15

Table XXVI. DATE FIRST FRUIT WAS SET

Soil No.	A	B	C	D	E
1		April 28		April 29	
2			April 28		
3		April 27	April 18	April 9	
4		March 23	*	March 25	April 15
5		March 12	March 21	March 23	April 15

* This plant had growth fasciation.

Table XXVII. NUMBER OF BLOSSOMS

Soil No.	A	B	C	D	E
1	0	8	0	10	0
2	0	1	2	5	2
3	0	9	9	9	11
4	0	10	13	9	14
5	2	14	15	16	14

Table XXVIII. NUMBER OF FRUIT SET

Soil No.	A	B	C	D	E
1	0	1	0	1	0
2	0	0	1	0	0
3	0	1	1	1	0
4	0	2	0	1	1
5	0	1	3	5	3



Fig. 4. Plants of the A series 42 days after transplanting. Left to right: Soils 1,2,3,4, and 5.



Fig. 5. Plants of the B series 42 days after transplanting. Left to right: Soils 1,2,3,4, and 5.



Fig. 6. Plants in soil 1 42 days after transplanting. Left to right; Series A, B, C, D, and E.



Fig. 7. Plants in soil 2 42 days after transplanting. Left to right: Series A, B, C, D, and E.



Fig. 8. Plants in soil 3 42 days after transplanting. Left to right: Series A, B, C, D, and E.



Fig. 8. Plants in soil 4 42 days after transplanting. Left to right: Series A, B, C, D, and E.



Fig. 10. Plants in soil 5 42 days after transplanting. Left to right: Series A, B, C, D, and E.



Fig. 11. Roots of plants 93 days after transplanting. Top row: Soil I. Second row: Soil 2. Third row: Soil 3. Fourth row: Soil 4. Fifth row: Soil 5.
Left to right, in each row: Series A, B, C, D, and E.

SUMMARY

All of the soils used contained a sufficient amount of available nitrogen and potash. With the exception of number 1, each was low in phosphoric acid.

Nitrate of soda and muriate of potash used together failed to produce as much plant response as when used with calcium metaphosphate.

Each of the soils responded positively to calcium metaphosphate, used with nitrate of soda and muriate of potash, from the standpoint of plant growth, earliness of blossoming, number of blossoms, earliness of fruit setting, and number of fruit set.

No significant difference was found between the response from 50 pounds, 100 pounds, 200 pounds, and 400 pounds of calcium metaphosphate per acre.

Comparable results were not obtained from plants grown in soil number 1 due to the fact that it was infested with tomato wilt.

The two soils of the red-colored type were more productive than either the "Barrens" type or DeKalb sandy type.

The results of experiments conducted at the various state experiment stations have shown that phosphate fertilizer increased crop production in almost every trial.

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