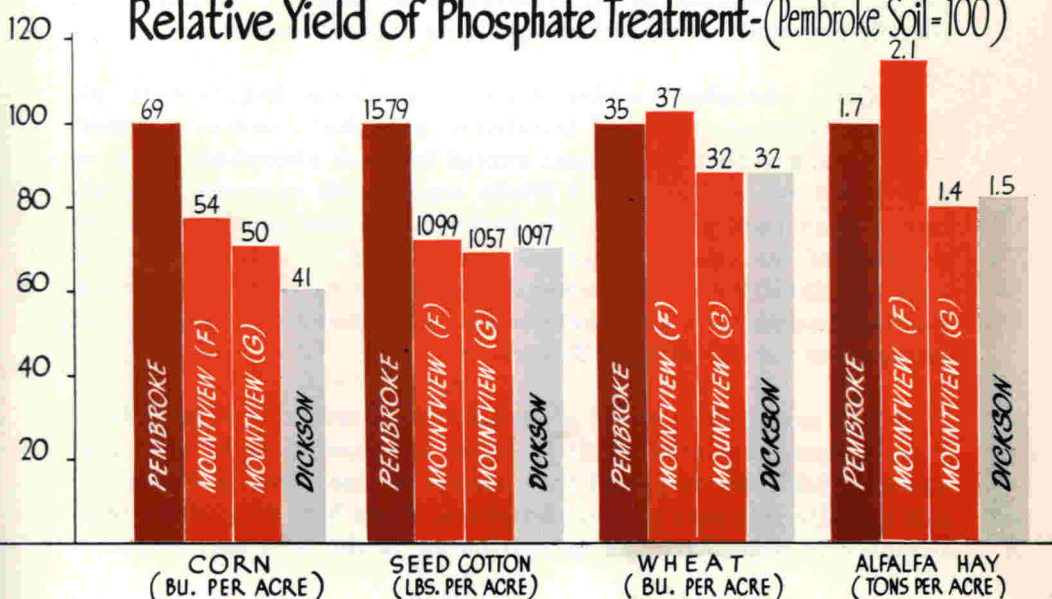


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Phosphates In Crop Rotations In Lawrence County

by O. H. Long

Relative Yield of Phosphate Treatment-(Pembroke Soil=100)



7- to 10-Year Average Yields of Four Crops at Four Locations

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Summary

● The importance of phosphate in a fertilization program in a rotation of corn, cotton, wheat, and alfalfa was studied at four locations in Lawrence County over a 10-year period, 1950-1959. The soils represented are Pembroke, Dickson, and Mountview. The latter two are widely distributed over the Highland Rim area of Tennessee and occupy a large percentage of its cleared acreage.

● The results show that a moderate application of concentrated superphosphate (40 pounds of P_2O_5 per acre per year) resulted in increases over the unphosphated treatment of 8 to 31 bushels of corn, 160 to 650 pounds of seed cotton, 9 to 23 bushels of wheat, and $\frac{1}{2}$ to 1 ton of alfalfa hay. The cost of this amount of phosphate, at current prices, is \$2.83 per acre. The cost of the complete fertilizer treatment—nitrogen, phosphate, and potash—ranged from \$6.44 per acre per year on alfalfa to \$16.59 on corn. Since nitrogen and potash were applied to all treatments at uniform overall rates, specific responses to these two nutrients are not known.

● Other phosphates under study in these experiments were calcium metaphosphate, fused tricalcium phosphate, ordinary superphosphate, and rock phosphate; except for rock phosphate, all gave a satisfactory performance. While some yield response was obtained from rock phosphate, its performance was considerably under that of the other phosphates, even though it was applied at a rate $2\frac{1}{2}$ times the other phosphates in terms of P_2O_5 equivalence. For this reason rock phosphate is not recommended as a source of phosphorus for the soils of Tennessee.

● Increasing the rate of phosphate fertilization to 80 pounds of P_2O_5 per acre resulted in little or no increase in yield over that obtained with the 40-pound rate, except at one location where the soil initially was very low in phosphate. Even here 85% of the total response to phosphate can be attributed to the first increment.

● When phosphate additions were discontinued after several years of application, 1 or 2 years elapsed before crop yields declined materially. By the third year the decline was appreciable, but remained considerably above the yield of the no-phosphate treatment.

● The rate of phosphate fertilization was reflected in the available phosphorus level of the soil as indicated by chemical tests made on samples collected at the conclusion of the experiments.

The soils also varied widely in reaction (pH) and available potassium both among and within locations, depending on type of soil, liming history, and level of crop production.

● The three soils varied considerably in the production of some of the crops. However, while the Dickson and Mountview soils were much inferior to the Pembroke soil in the production of corn and cotton, all three soils were about equal in the production of wheat.

● The practical application of these findings is discussed.

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Phosphates in Crop Rotations in Lawrence County

by
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Phosphate is needed as a fertilizer on perhaps 90% of the agricultural soils of the State. Excepting certain soils naturally high in phosphate, found mainly in the Outer Basin area of Middle Tennessee and in the bottom lands along the Mississippi River in west Tennessee, most crops respond to phosphate. However, more information is needed on how much phosphate can be applied economically to the different crops and the relative value of different phosphates.

The Rotations

In order to obtain more information on these two points some rotation experiments were initiated on four private farms in Lawrence County, Tennessee. Three of these rotations were started in the spring of 1950 and the fourth in late summer of 1952. Two were located on Mountview silt loam, one on Dickson silt loam, and



Figure 1.—General view of rotation on Pembroke soil, photographed in early June, 1956. Corn is growing on Range 1 in foreground. Cotton is on Range 2, backed up by 3-, 2-, and 1-year-old stands of alfalfa on Ranges 3, 4, and 5. In the far background wheat is about ready for harvest on Range 6.

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one on Pembroke silt loam. The crops in the rotation were corn, cotton, wheat, and alfalfa, and followed each other in that order. A general view of one of these experimental areas is shown in Figure 1.

On the Pembroke and Mountview soils alfalfa was allowed to remain on the land 3 years, and on the Dickson soil for 2 years. Four or six ranges of land—or land strips—were laid off and divided into plots of 1/60- or 1/50-acre in size. Such an arrangement permitted each crop of the rotation to be represented each year. For example, after the rotation was in full operation, one range would be in corn, another in cotton, a third in wheat, and three other ranges in alfalfa, varying in age of stand from 1 to 3 years. Thus, 6 years were required to complete one cycle of the rotation on the Pembroke and Mountview soils. On the Dickson soil both corn and cotton grew on the same range in a split-plot arrangement. These two crops were followed by wheat. After wheat harvest the land was prepared and seeded that same year to alfalfa, which was allowed to remain on the land for 2 years. Then the land was turned in the fall and planted to corn and cotton the next spring, starting a new 4-year cycle of the rotation.

In experiments of this nature, having the same crops at all locations with all crops of the rotation represented every year is a distinct advantage. Such an arrangement subjects all crops to the same weather conditions each year, thus permitting certain comparisons to be made in their yields on the different soils in the same year. It also provides a better evaluation of the effects of average environmental conditions on each crop.

In the harvesting of corn and cotton for yield determinations the two outside rows of a 5- or 6-row plot were eliminated in order to avoid possible border effects of the various fertilizer treatments. In the case of wheat and alfalfa, 1-foot paths were made to separate the plots and the entire plot area was harvested for yield determinations.

The Soils

The Pembroke soil is one of the better upland soils of the Highland Rim area. The upper part of the solum is developed from loess and the lower part is residuum from high-grade limestones. If uneroded, the surface layer is a dark brown silt loam and the subsoil a silty clay loam, grading in color from a yellowish-red to a dark red with depth. Internal drainage is good. Sizable areas of this soil are found east, west, and north of Lawrenceburg, but it

constitutes only a minor part of the land area of Lawrence County. This "red" land is highly prized by farmers and is devoted largely to cotton, corn, wheat, and some alfalfa.

The Dickson and Mountview are also upland soils, but are developed from a thin mantle of loess over a cherty limestone residuum. The surface layer is a grayish brown silt loam and the subsoil a pale yellow. No great change in clay content with depth was observed and the texture remained a silt loam to a depth of 30 inches or more. Drainage through the soil profile in the Mountview is good; the Dickson is moderately well-drained. The chief difference between the Dickson and the Mountview is the presence of a compact layer (fragipan) at a depth of about 2 feet in the former; the Mountview has no such well-defined layer. The acreage of these two soils in Lawrence County is extensive. They also are devoted largely to corn, cotton, and wheat, but are lower than Pembroke in natural fertility, particularly with respect to available potassium and calcium. Generally speaking, Dickson and Mountview are rated much lower than Pembroke in productivity.

The Fertilizer Treatments

These experiments were initiated to study the effect of phosphate fertilization on crop production. Nitrogen and potash were not under study, but were applied to all treatments, including the unphosphated check, at uniform rates; ammonium nitrate (neutralized with limestone) and muriate of potash were the materials used.

Concentrated superphosphate (48% P_2O_5), calcium metaphosphate (64%), fused tricalcium phosphate (29%), and rock phosphate (30%) were the phosphates under test. At one location, where rock phosphate was not included, ordinary 20% superphosphate was used. The number of phosphate treatments varied from 5 to 9 at the different locations. Concentrated superphosphate was the standard for comparison and the performance of the other phosphates is expressed as a percentage of this material. The standard rate of phosphate application for the so-called "available" phosphates was 40 pounds of P_2O_5 per acre per year. This rate is equivalent to 200 pounds of 20% superphosphate, or lesser amounts of the other phosphates, depending on their total P_2O_5 content. These "available" phosphates were applied ahead of planting of each crop—in the row for corn and cotton and broadcast for wheat and alfalfa.

Where rock phosphate was used, it was applied broadcast at the beginning of the rotation cycle and again at or near its completion.

The rate of application of rock phosphate was $2\frac{1}{2}$ times that of the "available" phosphates in terms of P_2O_5 equivalence. For example, the concentrated superphosphate treatment at a 40-pound-per-acre-per-year P_2O_5 rate would receive 240 pounds of P_2O_5 over the 6-year cycle of a rotation. The rock phosphate application rate for the same 6-year period would be 600 pounds of P_2O_5 , or 2000 pounds of the material per acre. In one treatment rock phosphate was supplemented with a small amount of concentrated superphosphate. In this treatment rock phosphate was applied broadcast at the rate of 1500 pounds per acre at the beginning of the experiment and this was supplemented with 60 pounds of P_2O_5 in the form of concentrated superphosphate to corn, cotton, and wheat—20 pounds to each crop.

All treatments, except where rock phosphate was the sole source of phosphorus, were replicated three times. There was only one replication of the unsupplemented rock phosphate treatment. These phosphate treatments were applied until the fall of 1956. Then some changes in fertilization were made at three locations, which will be discussed later. No changes were made in the experiment on the Mountview soil that was started in 1952.

The rate of nitrogen fertilization on corn was 90 pounds of N per acre; on cotton and wheat, 50 pounds; and on alfalfa at seeding, 30 pounds. The nitrogen applications were divided on the corn, cotton, and wheat crops—25 pounds of N being applied at planting and the remainder as a side- or top-dressing. Nitrogen on alfalfa was applied only at seeding.

The rate of potash fertilization originally was 50 to 75 pounds of K_2O per acre per year, depending on the soil test. Later this rate was increased on alfalfa at some locations.

Both nitrogen and potash were applied to all treatments of the same crop at the same time and in the same manner. This means that they were applied in the row on the row crops or broadcast on the broadcast-sown crops, regardless of whether or not they were mixed with a phosphate.

In preparing the land for alfalfa, the "available" phosphates were applied at a rate 2 or 3 times the annual rate, depending on whether the crop was to remain on the land 2 or 3 years. The potash application was for a 2-year period. Where alfalfa remained on the land for 3 years a potash top-dressing was made in the spring of the third production year. Borax also was applied to alfalfa at seeding at a rate of 20 pounds per acre.

6-Year Rotation of Corn, Cotton, Wheat, and Alfalfa (3 Years) on Pembroke Silt Loam

The rotation on Pembroke silt loam was started in the spring of 1950 by turning the land, laying off six ranges and applying rock phosphate to the plots designated to receive this treatment. This material was disked into the soil and two ranges were prepared and planted—one to corn and the other to cotton. Soybeans were planted as a temporary crop on the other four ranges. In late summer the soybeans were plowed under and one range was seeded to wheat and the other three ranges to alfalfa.

This soil previously had been limed by the farmer-cooperator, and at the beginning of the experiment the surface layer tested pH 6.8. The pH of the subsoil (6-12") was 5.2. No lime was applied during the 10-year period that the experiment was in progress. The pH of the surface soil at the conclusion of the experiment in 1960 was in the range 6.3 to 6.6. The available phosphate level was low to medium and potash high (335 pounds of K per acre).

The year-by-year and average yields for the entire period of all four crops with and without phosphate fertilization are shown in Table 1.

Table 1.—Acre Yields of Crops in a 6-Year Rotation Under Unphosphated and Phosphated Conditions, 1950-1959.

Pembroke silt loam

Year	Corn ¹		Seed cotton		Wheat		Alfalfa hay	
	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²
	Bu.	Bu.	Pounds	Pounds	Bu.	Bu.	Tons	Tons
1950	64.6	62.6	758	1076	...	...	...	...
1951	36.7	46.3	983	1214	16.8	18.8	0.57	0.90
1952	42.9	51.8	958	914	21.7	34.5	0.78	1.06
1953	43.9	62.4	1488	1872	26.0	42.8	1.58	3.16
1954	26.8	32.2	622	878	15.5	33.8	1.00	1.88
1955	70.0	99.2	1150	1842	16.4	31.7	0.90	1.46
1956	55.3	70.7	1330	1760	20.7	40.0	0.70	1.55
1957	36.7	59.3	1158	1311	23.1	41.9	0.77	1.27
1958	73.5	98.6	1469	2275	24.2	38.2	0.93	1.68
1959	79.6	107.4	1734	2650	21.5	33.1	1.18	2.43
Av.	53.0	69.1	1165	1579	20.7	35.0	0.93	1.71

¹Nitrogen applications were discontinued on corn during the period 1954-1958.

²The phosphate fertilization was at a rate of 40 pounds of P_2O_5 per acre per year, using concentrated superphosphate.

Corn showed some yield response to applied phosphate every year except the first. The average yield for the 10-year period was 53 bushels where no phosphate was applied and 69 bushels where concentrated superphosphate was applied annually at the 40-pound P_2O_5 rate. Cotton, wheat, and alfalfa responded even more to phosphate than did corn. The average increase in yield of seed cotton attributable to phosphate was about 400 pounds; wheat and alfalfa yields were almost doubled. Where phosphate was applied seed cotton yields averaged 1579 pounds per acre; wheat, 35 bushels; and alfalfa hay, 1.71 tons per acre.

The somewhat disappointing yields of alfalfa require some discussion. Excluding 1953 and 1959 the hay crop averaged less than $1\frac{1}{2}$ tons per acre. This low yield probably cannot be related to a low fertility status of this soil. Exchangeable calcium and potassium were quite high; moreover, drainage and aeration are good, as indicated by the reddish subsoil. While summer droughts were a factor, it is the writer's opinion that this soil was too level for best alfalfa production. Despite the good internal drainage, water would collect and stand temporarily in small local depressions during periods of heavy or prolonged rains. In such spots, crabgrass would flourish and often alfalfa would disappear entirely. It has often been observed that alfalfa does best on slightly rolling land where water does not collect on the surface. While it may produce well for a time, the stand will soon disappear in depressions or at the foot of slopes, but will persist for several years on higher ground. It should be borne in mind that the alfalfa yields in Table 1 and in the tables which follow are averages of all ages of stand (in this case 1-, 2-, and 3-year-old stands), unless otherwise specified.

In the dry summer of 1954 corn production on the phosphated treatment was only 32 bushels and seed cotton only 878 pounds per acre. Wheat yields in 1954, however, held up quite well. This was because wheat had matured and had been harvested before the summer drought set in.

The nitrogen applications were discontinued on corn beginning in 1954. The reason for doing this was the belief that a 3-year-old stand of alfalfa which preceded this crop would supply the corn's nitrogen requirements. Justification for this belief is the yield record of corn after 1954. In fact, corn production was much better in the second half than in the first half of the 10-year period. This was undoubtedly due in part to better moisture conditions, but the fact that corn produced a 100-bushel crop in 1955 and again in 1958

without added nitrogen testifies to the efficacy of alfalfa in enriching the available nitrogen content of the soil. Nitrogen was applied to the 1959 corn crop because it followed a very poor stand of alfalfa.

4-Year Rotation of Corn (or Cotton), Wheat, and Alfalfa (2 Years) on Dickson Silt Loam

The rotation on Dickson silt loam² also was started in 1950. It differs from the rotation on the Pembroke soil only in that corn and cotton were grown on the same range in a split-plot arrangement and that alfalfa was allowed to remain on the land for only 2 years. The shortening of the stand life of alfalfa on Dickson by 1 year was deemed advisable in view of the compact layer in the subsoil, which impedes internal drainage and which could limit production and longevity of stand.

This soil also had been limed previously by the cooperator but was re-limed at the beginning of the experiment at a rate of 1 ton of ground limestone per acre. The pH of the plow layer prior to reliming was 5.3, and of the subsoil, 4.7. The phosphorus level of the surface layer was medium but available potassium was very low.

The year-by-year and average yields for the entire period of all four crops with and without phosphate fertilization are shown in Table 2.

²Although mapped as Dickson this site includes some Sango.

Table 2.—Acre Yields of Crops in a 4-Year Rotation Under Unphosphated and Phosphated Conditions, 1950-1959.

Dickson silt loam

Year	Corn ¹		Seed cotton ¹		Wheat		Alfalfa hay	
	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²
	Bu.	Bu.	Pounds	Pounds	Bu.	Bu.	Tons	Tons
1950	38.9	54.9	177	336	..	..	..	..
1951	6.6	15.1	753	888	(Spring oat hay)		0.34	0.46
1952	23.4	19.0	1101	1212	16.4	27.6	0.58	0.70
1953	48.3	52.4	972	1206	21.5	38.8	0.64	1.73
1954	7.7	12.1	537	582	19.9	30.8	0.49	1.53
1955	28.6	47.2	954	1311	11.7	27.8	0.65	1.31
1956	25.2	43.1	699	823	22.6	34.9	0.75	1.47
1957	41.5	47.1	801	1002	18.0	30.6	0.55	1.51
1958	30.5	58.3	1296	1683	16.2	27.4	0.64	1.67
1959	36.8	63.9	1227	1923	17.2	33.9	1.35	3.21
Av.	28.8	41.3	852	1097	17.9	31.5	0.67	1.51

¹Nitrogen applications were discontinued on corn and cotton beginning in 1954.

²The phosphate fertilization was at a rate of 40 pounds of P_2O_5 per acre per year, using concentrated superphosphate.

All crops showed a marked response to phosphate; alfalfa yields were more than doubled and wheat almost so by an annual phosphate application of 40 pounds of P_2O_5 per acre. With phosphate, average acre yields for the entire period were as follows: corn 41.3 bushels; seed cotton, 1097 pounds; wheat, 31.5 bushels; and alfalfa 1.5 tons.

Attention is called to the fact that corn and cotton yields dropped sharply in 1951 and 1954—2 years characterized by prolonged summer droughts. In these 2 years even phosphated corn produced only 12 to 15 bushels per acre, and seed cotton approximately 600 to 900 pounds. Note, however, that in the dry year of 1954 wheat yields were about as good as average, again demonstrating how the early maturity of this crop allows it to escape summer droughts.

Certain comparisons of crop yields on this Dickson soil with those on the previously-discussed Pembroke soil are of interest. These two experimental sites were located less than 3 miles apart, and it is reasonable to assume that on the average they had essentially the same weather conditions. Over the 10-year period corn production on Dickson under phosphated conditions was 60% that on Pembroke; cotton production, 69%; wheat production, 90%; and alfalfa production, 88%. Thus, the Dickson soil compares most favorably with the Pembroke soil in the production of wheat and least favorably in the production of corn. These findings have considerable significance and will be discussed later.

The relatively favorable showing of alfalfa on Dickson as compared to that on Pembroke is more a matter of disappointing results on the latter rather than their exceeding expectations on the former.

The last year (1959) was by far the best year for corn, cotton, and alfalfa production on the Dickson soil. The corn yield at one of the higher fertilizer rates was 68 bushels, seed cotton approached a 2000-pound yield level, and first-year alfalfa produced almost 5 tons of hay. These figures indicate the yield possibilities on this soil when growing conditions are favorable.

6-Year Rotation of Corn, Cotton, Wheat, and Alfalfa (3 Years) on Mountview Silt Loam (Freemon Farm)

This rotation on Mountview soil was started at the same time as those on the Pembroke and Dickson soils already discussed. The sequence of crops, fertilizer materials used, and rate of fertilization

were the same as those on the Pembroke soil with the following exceptions: 1) Ordinary 20% superphosphate was substituted for rock phosphate, and 2) the annual rate of potash fertilization was increased from 50 to 75 pounds of K_2O per acre, beginning with the seedings of alfalfa and wheat in 1954. The reason for eliminating the rock phosphate treatment was that a previous owner of the land had applied rock phosphate 8 years before the rotation experiment began. This owner had at the same time applied lime at the rate of about 8 tons per acre. Soil tests made on samples taken at the beginning of the experiment indicated a very high phosphorous level and a pH of 7.3. Available potassium was very low.

An abnormality in the growth of corn was observed the first year. Suspecting a zinc deficiency, brought about by the high phosphate and lime applications, zinc sulfate was applied as a sidedressing to certain rows. This application partly corrected the deficiency symptoms. Further confirmation of zinc deficiency was obtained the second year (1951) when corn was planted on another range. Before this planting, zinc sulfate was mixed with the fertilizer and applied in the two outside rows of each of the five-row plots. The three center rows were fertilized similarly except for zinc sulfate. As an average of 15 plots the corn yields were about 13 bushels higher where zinc sulfate was added than where it was withheld. Thereafter zinc sulfate was added to the fertilizer for corn and applied as an overall treatment, and no further indication of zinc deficiency was observed. Symptoms of zinc deficiency were never observed on cotton, wheat, and alfalfa.

The year-by-year and average yields for the entire period of all four crops with and without phosphate fertilization are shown in Table 3. As in the other experiments, the yields on the phosphated treatment are those obtained with concentrated superphosphate at the 40-pound- P_2O_5 rate.

Corn and cotton showed no response to phosphate in the first 2 years of the experiment, and wheat and alfalfa showed very little. In the third year (1952) a prolonged and serious summer drought reduced the yields of corn and alfalfa sharply. Corn was caught at its critical time of silking and tasseling and was practically a complete failure. Wheat escaped this summer drought and made a satisfactory yield. The summer of 1952 was by far the driest at this location, whereas the summers of 1951 and 1954 were the driest at the other two locations. This test on Mountview was in the southern part of Lawrence County, located about 12 miles from the two experiments discussed previously.

Table 3.—Acre Yields of Crops in a 6-Year Rotation Under Unphosphated and Phosphated Conditions, 1950-1959.

Mountview silt loam

(Freemon farm)

Year	Corn ¹		Seed cotton		Wheat		Alfalfa hay	
	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²	No Phosphate	Phosphated ²
	Bushels	Bushels	Pounds	Pounds	Bushels	Bushels	Tons	Tons
1950	45.9	41.8	387	379	..	..	..	..
1951	62.7	54.6	1100	1139	19.0	21.8	0.67	0.73
1952	2.1	1.1	875	1011	31.5	36.8	1.25	1.31
1953	35.1	43.4	836	1033	32.9	41.5	2.30	2.82
1954	33.7	33.9	697	847	29.5	40.4	1.54	2.13
1955	83.6	97.0	1150	1244	27.2	37.8	1.36	1.99
1956	45.6	58.6	944	1014	29.9	40.3	0.88	1.80
1957	32.1	38.6	719	938	23.9	33.3	0.93	1.63
1958	54.1	80.0	1178	1716	30.6	39.2	1.65	2.38
1959	69.4	92.6	1494	1667	24.7	39.3	2.55	3.63
Av.	46.4	54.2	938	1099	27.7	36.7	1.46	2.05

¹Nitrogen applications were discontinued on corn beginning in 1954.

²The phosphate fertilization was at a rate of 40 pounds of P_2O_5 per acre per year, using concentrated superphosphate.

Crop response to phosphate at this site was the least obtained at the four locations; nevertheless its use was highly profitable on all crops. As an average of the entire period, an annual application of concentrated superphosphate at a rate of 40 pounds of P_2O_5 per acre resulted in a corn yield of 54.2 bushels, a seed cotton yield of 1099 pounds, a wheat yield of 36.7 bushels, and an alfalfa hay yield of 2.05 tons per acre. These yields represent increases over the unphosphated treatment of about 8 bushels of corn, 160 pounds of seed cotton, 9 bushels of wheat, and $\frac{1}{2}$ ton of alfalfa. Thus, wheat and alfalfa were more responsive to phosphate than were corn and cotton.

Since this Mountview soil is so similar to the previously-discussed Dickson soil in texture, color and parent material, a comparison of crop yields on the two soils is in order. As stated previously, these two soils differ mainly in that Dickson has a distinct brittle pan about 2 feet below the surface, while Mountview has no such pan development. Therefore, internal drainage in the Mountview should be better than that in the Dickson. Corn yields on the phosphate treatment were about 13 bushels higher on Mountview, while cotton yields were almost exactly the same on the two soils. This would indicate that Dickson is relatively better suited to cotton than to corn. Excellent corn was produced on

Mountview in 1955, 1958, and 1959, with yields ranging between 80 and 97 bushels per acre. These high yields were attained without added nitrogen, again attesting to the beneficial effect of alfalfa, a fact which has already been mentioned. On the phosphate treatment wheat also yielded about 5 bushels higher on the Mountview soil, and alfalfa yields were considerably higher on Mountview under both phosphated and unphosphated conditions.

6-Year Rotation of Corn, Cotton, Wheat, and Alfalfa (3 Years) on Mountview Silt Loam (Gower Farm)

The rotation on the J. L. Gower farm was not started until the fall of 1952, 2 years later than the other rotations in Lawrence County. It also was on Mountview silt loam, but the soil was shallower and contained more chert in the subsoil than that on the Freemon farm. The phosphate level was very low and available potash low (125 lb. K per acre). The experiment on the Gower farm was on about a 3% northeast-facing slope, while that on the Freemon farm was on a site that was practically level. The same 6-year rotation was followed as was already in progress on the Pembroke and the other Mountview soil. However, from the beginning the various phosphates were applied at two rates: 40 and 80 pounds of P_2O_5 per acre per year. In addition, a concentrated superphosphate treatment was included in which all of the potash applied was in the form of sulfate of potash. This treatment was added to determine whether sulfur was important to crop production in this area, since none of the other fertilizer treatments contained this element. The 90-pound N application was made to corn throughout the duration of this experiment; potash was applied at a uniform rate of 75 pounds of K_2O per acre per year.

The year-by-year and average yields for the entire period of all four crops with and without phosphate fertilization are presented in Table 4. Yields are shown for both the 40- and 80-pound P_2O_5 rates.

One of the most striking features of these results is the extremely low yields of crops on the no-phosphate treatment. Crop response to applied phosphate at this site was the most pronounced of all the four locations, three- to seven-fold increases in yield being obtained from an application of phosphate. The degree of this response on corn, cotton, and wheat is well illustrated in Figures 2, 3, and 4.

Table 4.—Acre Yields of Crops in a 6-Year Rotation Under Unphosphated and Phosphated Conditions, 1953-1959.

Mountview silt loam
(Gower farm)

Year	Corn ¹			Seed cotton			Wheat			Alfalfa hay		
	No phos- phate	40 lb. P ₂ O ₅ per acre per year ²	80 lb. P ₂ O ₅ per acre per year ²	No phos- phate	40 lb. P ₂ O ₅ per acre per year ²	80 lb. P ₂ O ₅ per acre per year ²	No phos- phate	40 lb. P ₂ O ₅ per acre per year ²	80 lb. P ₂ O ₅ per acre per year ²	No phos- phate	40 lb. P ₂ O ₅ per acre per year ²	80 lb. P ₂ O ₅ per acre per year ²
		Bushels			Pounds			Bushels			Tons	
1953	4.9	15.5	17.0	292	669	900	13.0	21.9	22.2	0.11	0.78	0.96
1954	11.6	19.3	21.9	300	564	617	6.0	28.7	35.6	0.03	0.76	0.78
1955	26.5	61.5	66.3	303	1192	1428	5.0	30.6	30.3	0.32	1.25	1.46
1956	25.2	55.7	59.2	727	1630	1777	3.8	32.7	39.4	0.11	1.25	1.48
1957	15.8	55.4	54.3	220	736	794	9.3	28.5	29.3	0.37	1.49	2.13
1958	23.7	63.0	72.0	300	1203	1172	16.3	35.3	36.5	0.40	2.00	2.43
1959	24.3	76.0	80.6	703	1408	1391	8.1	43.0	45.3	0.25	2.11	2.46
Av.	18.9	49.5	53.0	406	1057	1154	8.8	31.5	34.1	0.23	1.38	1.67

¹Corn was fertilized with nitrogen at a rate of 90 pounds of N per acre for the duration of this rotation.

²Concentrated superphosphate was the phosphate used in this comparison.



Figure 2.—Unphosphated versus phosphated corn on Mountview silt loam (Gower farm). The plot on the left was fertilized only with nitrogen and potash. The plot on the right received a complete nitrogen-phosphate-potash fertilizer treatment. (Photographed June 30, 1959.)

In this connection a comparison of crop yields and the degree of response to applied phosphate on this and the other Mountview site seems warranted. Before starting the experiment on the Free-mon farm, the area had been cropped regularly to corn, cotton, and wheat, each with moderate applications of fertilizer. In contrast, the field on the Gower farm had been in unimproved pasture for many years and had not been fertilized or limed within the memory of the owner. This "pasture" consisted largely of rat-tail plantain (*Plantago aristata*), with a scattering of annual lespedeza. The predominance of rat-tail plantain is in itself a sign of a low fertility level.

One of the first operations on this field was an application of ground limestone at the rate of 3 tons per acre. A check on the soil reaction made in 1956 revealed that the pH (less than 6.0) was still too low for best alfalfa production. Therefore the area was re-limed one range at a time, beginning in March 1957 and continuing to March 1959. By this time all ranges had been re-limed except

one. Dolomitic limestone was applied at a rate of 2 tons per acre. Thus, in the course of the experiment 5 tons of lime were applied.

By comparing Table 3 with Table 4 one is impressed with the



Figure 3.—Phosphate versus no phosphate on cotton on Mountview silt loam (Gower farm). Plot on left received a complete NPK fertilizer treatment (80 pounds of P_2O_5 as concentrated superphosphate, or CSP); plot on right received the same amount of nitrogen and potash but no phosphate. An unphosphated plot of corn can also be seen at the extreme upper left in an adjoining range. (Photographed June 30, 1959.)



Figure 4.—A general view of the rotation on Mountview silt loam (Gower farm), showing corn, cotton, and wheat on separate ranges from left to right. Note the small amount of wheat in the shock on the unphosphated plot (second plot from camera). (Photographed June 30, 1959.)

wide difference in crop yields on the unphosphated treatment at the two locations. Where phosphate was withheld on the Gower farm corn yields averaged only about 19 bushels; seed cotton, about 400 pounds; wheat, about 9 bushels; and alfalfa hay, about one-quarter of a ton. These compare with a corn yield of about 46 bushels, a seed cotton yield of about 950 pounds, a wheat yield of about 28 bushels, and an alfalfa hay yield of about 1½ tons on the unphosphated treatment on the Freemon farm. Thus, the unphosphated treatment yields on the Freemon farm were from about 2 to 6 times greater than those on the Gower farm. In fact, on the Gower farm an annual phosphate application of 40 pounds of P_2O_5 was required in order to obtain yields comparable to those obtained without phosphate on the Freemon farm. Even at the 80-pound rate crop yields on the Gower farm were lower than those at the 40-pound rate on the Freemon farm. These results demonstrate differences due to past management in the productivity of soils, even of the same name and type.

The Relative Performance of Different Phosphates

It was mentioned earlier that five different phosphates were used in the rotation experiments in Lawrence County. Up to this point the discussion on crop response to phosphate has been confined to that obtained with concentrated superphosphate (CSP), which was the standard for comparison in all the experiments. The other phosphates were calcium metaphosphate (CMP), fused tricalcium phosphate (FTP), rock phosphate (Rock), and ordinary superphosphate (OSP). The latter was used instead of rock phosphate in only one experiment. These abbreviations will frequently be used for the various phosphates in the rest of the discussion.

The performance of the various phosphates can perhaps best be shown by expressing the crop yields obtained with each phosphate in terms of percent of yield of that obtained with CSP, which was selected as the standard. This has been done, and the results are presented in bar-graph form in Figures 5, 6, 7, and 8. It should be noted that the average yield of each crop obtained with CSP at an annual rate of 40 pounds of P_2O_5 per acre is assigned a value of 100. The average yields obtained with the other phosphates or with all phosphates at a higher rate of P_2O_5 (Table 4) are expressed in terms of percent of this base yield. The actual yields obtained with CSP at the 40-pound P_2O_5 rate and with the no-phosphate check treatment can be ascertained by referring to their average yields in Tables 1 to 4. Since applications of CMP, FTP, and OSP were dis-

continued after 1956, their relative yields are in terms of CSP up to and including that year.

On the Pembroke soil (Figure 5), CMP and FTP compared favorably with CSP on all four crops, and while they were slightly

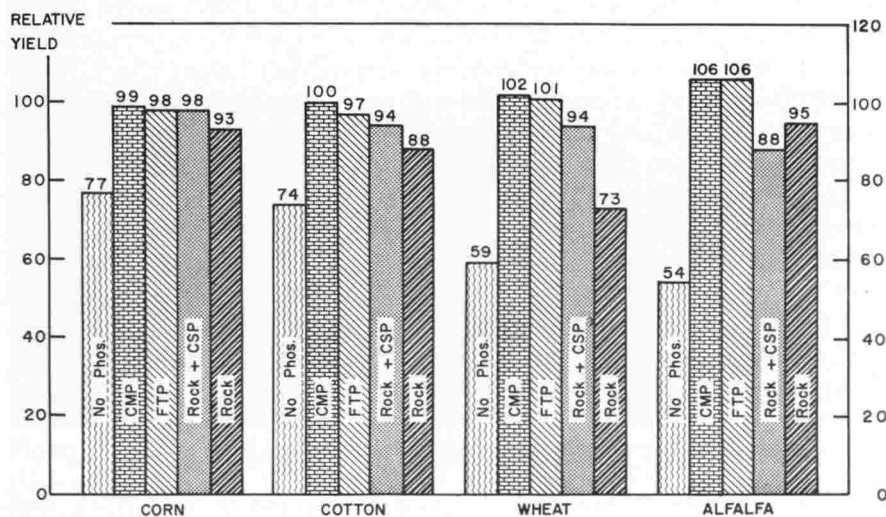


Figure 5.—Relative yields of four crops with different phosphate treatments on Pembroke silt loam, [Concentrated superphosphate (CSP) = 100]. CMP = Calcium metaphosphate, FTP = Fused tricalcium phosphate, Rock = Rock phosphate.

less effective than CSP on corn, they were slightly more effective on wheat and alfalfa. The differences are not significant in any case. The same cannot be said for the rock phosphate treatments, either when rock was used alone or when it was supplemented with 20 pounds of P_2O_5 from CSP to each of the corn, cotton, and wheat crops. Both rock phosphate treatments were decidedly inferior to the other phosphates on cotton, wheat, and alfalfa. As an average of all crops, rock phosphate alone produced a yield 87% of that produced with CSP. Where it was supplemented with CSP the average yield was 94% that of CSP. These results were obtained despite the fact that the second applications of rock phosphate were made during the period 1955-1958, before the experiment was concluded. Thus, the total amount of rock phosphate applied was 2 tons per acre on the "Rock" treatment and 1½ tons on the "Rock + CSP" treatment. Moreover, there was no tendency for the relative yields on these treatments to improve with time. Rock phosphate was, however, of some value, since the average yield of all crops

on the unphosphated treatment was only 66% that of the base treatment.

The relative performance of the various phosphates on the Dickson soil is shown in Figure 6. Again, it will be observed that CMP

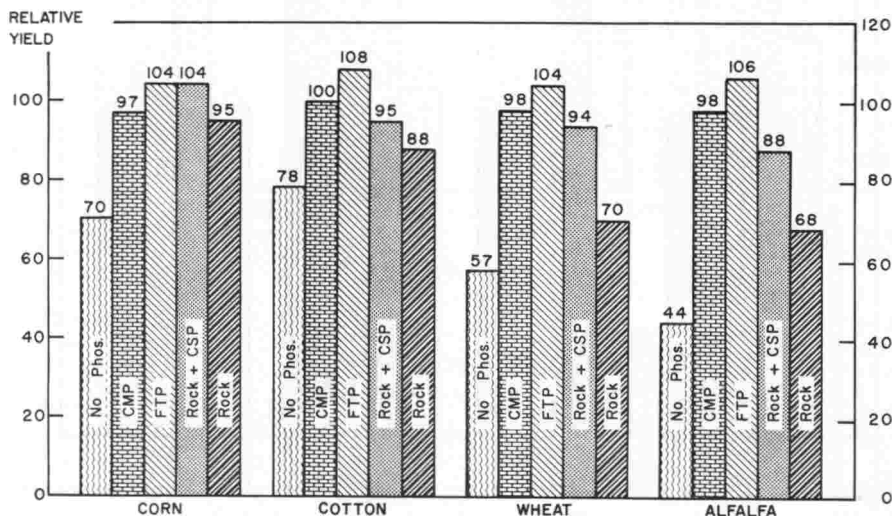


Figure 6.—Relative yields of four crops with different phosphate treatments on Dickson silt loam, [Concentrated superphosphate (CSP) = 100]. CMP = Calcium metaphosphate, FTP = Fused tricalcium phosphate, Rock = Rock phosphate.

and FTP compare favorably with CSP; in fact, the performance of FTP was superior to that of CSP on all crops, but not significantly so. On this soil also the performance of rock phosphate was inferior to that of the other phosphates, although the "Rock + CSP" treatment on corn was quite effective. As an average of all crops rock phosphate alone produced a yield 80% of that produced with CSP. Where it was supplemented with CSP the average yield was 95% that of the standard. The average yield of all crops on the unphosphated treatment was 62% that of the base treatment. The original rock phosphate applications were also repeated on this soil beginning in the spring of 1954. In fact, before the experiment was concluded, the third application had been made on 2 of the 4 ranges. Each application was at the rate of 1000 pounds of the material per acre where supplemented with CSP, and 1333 pounds when rock phosphate was the only phosphate source.

Figure 7 shows the relative performance of the various phosphates on Mountview silt loam on the Freemon farm. Ordinary

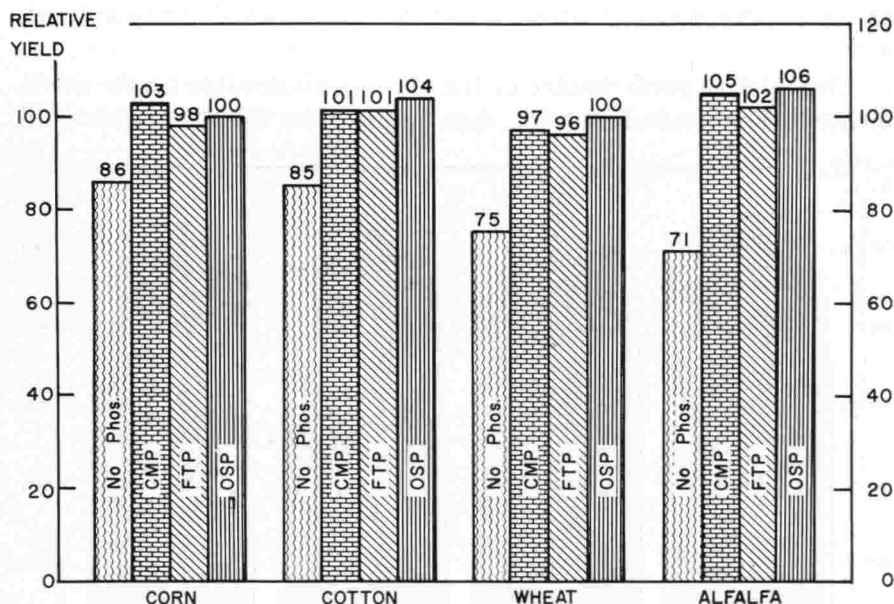


Figure 7.—Relative yields of four crops with different phosphate treatments on Mountview silt loam (Freemon farm), [Concentrated superphosphate (CSP) = 100]. CMP = Calcium metaphosphate, FTP = Fused tricalcium phosphate, OSP = Ordinary (20%) superphosphate.

superphosphate (OSP) was used instead of rock phosphate in this experiment. CMP, FTP, and OSP all compare favorably with CSP. As an average for all crops the relative yields with the different phosphates were as follows: CMP, 102; FTP, 99; and OSP, 103. The average relative yield on the unphosphated treatment was 79.

The inclusion of OSP as one of the phosphate sources provides some information on the sulfur status of this soil, particularly with respect to its adequacy in the production of crops. Since OSP contains about 11 percent sulfur (in the form of calcium sulfate) and the other phosphates little or none, it follows that this phosphate should be superior if sulfur were a limiting factor. Cotton in particular is sensitive to a deficiency of sulfur. Therefore, since yields of cotton as well as those of the other crops were essentially the same with the various phosphate treatments, it is safe to assume that sulfur was not a limiting factor in the course of this experiment.

The performance of the different phosphates on another Mountview soil (Gower farm) is shown in Figure 8. Here the phosphates

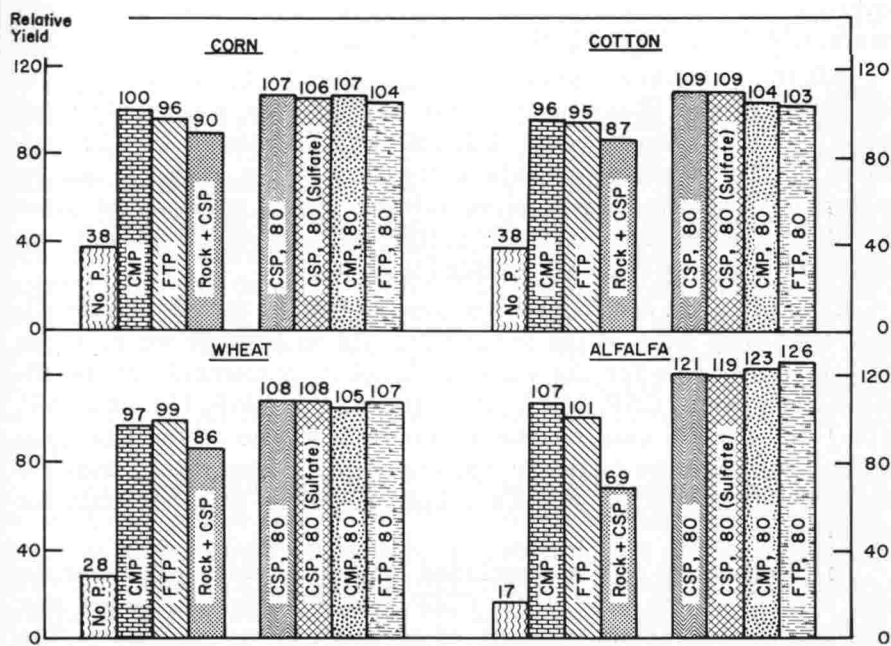


Figure 8.—Relative yields of four crops with different phosphate treatments on Mountview silt loam (Gower farm), [Concentrated superphosphate (CSP) at 40-pound P_2O_5 rate = 100]. CMP = Calcium metaphosphate, FTP = Fused tricalcium phosphate, Rock = Rock phosphate.

were compared at rates of 40 and 80 pounds of P_2O_5 per acre per year. The actual yields of the various crops obtained with CSP at the 40-pound P_2O_5 rate, as shown in Table 4, are assigned a relative yield of 100. The yields obtained with CSP at the 80-pound rate as well as the yields obtained with the other phosphates at both the 40- and 80-pound rates are expressed in terms of percentage of the base yield.

At the 40-pound- P_2O_5 rate there is some indication that CMP and FTP were slightly inferior on cotton, but equal to or slightly better than CSP on alfalfa. A possible explanation for this is the slower availability and fixation of CMP and FTP. This slowness in reaction might be an advantage with alfalfa where all of the phosphate for the 3-year stand was applied before seeding. The rock phosphate treatment was inferior to the other phosphates on all crops. Where it was supplemented with small amounts of CSP (on corn, cotton, and wheat), its relative yield was 86 to 90, but where no CSP supplement was added (on alfalfa) its relative yield was 69. As an

average for all crops the relative yields for the various treatments were: CMP, 100; FTP, 98; Rock + CSP, 83; and no phosphate, 30.

All the "available" phosphates appeared to be about equal in efficiency at the 80-pound- P_2O_5 rate. Two CSP treatments were used at this rate, one labeled "CSP, 80" and the other "CSP, 80 (sulfate)." The latter represents a treatment that received all its potash in the form of potassium sulfate. Since none of the other fertilizer treatments contained sulfur, this treatment permits an evaluation of crop response to this element.

Crop yields in every instance were higher at the 80-pound- P_2O_5 rate than they were at the lower rate. As an average for all crops the relative yields for the various phosphate treatments at the 80-pound rate were: CSP, 111; CSP (sulfate), 111; CMP, 110; and FTP, 110. As was the case on the Freemon farm, no advantage from adding sulfur to the fertilizer was observed. These results indicate that in this instance the soil's supply of sulfur was adequate for crop production.

In summary, it can be concluded that crop yields were essentially the same with CSP, OSP, CMP, and FTP, and therefore any one was as satisfactory a source of phosphorus as the others. The same cannot be said for rock phosphate either when used alone or when supplemented with small amounts of CSP. Evidence in the literature indicates that rock phosphate does best on acid soils and that plants vary in their ability to utilize the phosphorus in this material. The theories are that the soil acids will solubilize this material, if finely ground, at a rate sufficient to meet the crop's phosphorus requirement and that the legumes, alfalfa, and sweet clover in particular, are better "feeders" than the non-legumes. However, in these experiments, the performance of rock phosphate was poorer on the more acid Dickson soil than it was on the less acid Pembroke soil. Moreover, it gave a relatively better performance with corn than with alfalfa. Its poorest performance was with wheat, a cool-season crop.

These results, as well as others not reported here, explain why rock phosphate is not recommended as a source of phosphorus for the soils of Tennessee.

The Effect of Changes in Phosphate and Potash Fertilization on Crop Yields

When it was concluded that the performance of CSP, CMP, and FTP was essentially the same, it was decided to drop CMP and FTP from the experiments at three of the locations, but to continue

with CSP and rock phosphate. Discontinuing these two phosphates provided space to study other aspects of fertilization.

Therefore, before seeding alfalfa and wheat in the fall of 1956, CSP was applied at 80 pounds of P_2O_5 (double the normal rate) on the former CMP-treatment, while both CSP and potash were applied at double the normal rate on the former FTP-treatment.

Beginning with the corn and cotton crops in the spring of 1957, phosphate applications were discontinued on the old CMP-treatment. This will later be referred to as the "residual phosphate" treatment. On the old FTP-treatment, CSP was applied at the 80-pound rate. OSP also was applied at the 80-pound rate in the rotation on the Freemon farm. Nitrogen applications remained unchanged on all these treatments; potash applications were at the normal rate.

Crop yields following these changes are presented in Tables 5 to 9. Corn, cotton and wheat yields in treatments 1 and 2 are the same as those already presented in Tables 1 to 4 and are repeated only for comparing them with treatments 3, 4, and 5. (The alfalfa yields in treatments 1 and 2 do not agree with those presented previously, because in this case they represent stands of different age while in the other they represent all ages of stand.)

Table 5 contains a 2- to 3-year record of alfalfa production on areas seeded in late summer of 1956. Although alfalfa yields responded markedly to applications of phosphate, the higher rate of phosphate either with or without the higher rate of potash resulted in yields not much different from those obtained with the lower

Table 5.—Yields of alfalfa obtained on 3 soils following various rates of fertilizer applied before seeding the 1956 crop.

Tmt. No.	Fertilizer treatment*	Pembroke			Mountview			Dickson	
		1957	1958	1959	1957	1958	1959	1957	1958
		Tons of alfalfa hay per acre							
1	No phosphate	0.54	0.88	0.85	1.02	1.90	2.51	0.49	0.51
2	CSP, 40; single K ¹	1.21	1.32	1.53	1.64	2.27	3.39	1.70	1.50
3	CSP, 80; single K ¹	1.07	1.48	1.75	1.78	2.48	3.35	1.56	1.47
4	CSP, 80; double K ²	1.26	1.59	1.75	1.86	2.56	3.63	2.04	2.05
5	OSP, 80; double K ²	...	...	...	1.87	2.54	3.93	...	...
L.S.D. (5%)		0.24	0.43	0.16	0.42	0.27	0.49	0.55	0.53

*CSP = concentrated superphosphate. OSP = ordinary (20%) superphosphate.

¹Rate of potash fertilization was 50 pounds of K_2O per acre per year on the Pembroke and 75 pounds on the Mountview and Dickson.

²Rate of potash fertilization was 100 pounds of K_2O per acre per year on the Pembroke and 150 pounds on the Mountview and Dickson.

rate of phosphate. However, the higher rate of phosphate in the third year on the Pembroke soil, the higher rate of both phosphate and potash in the second and third years on the Mountview soil, and in the second year on the Dickson soil produced significantly higher yields than the lower rate. It should be remembered that the rate of phosphate was 2 to 3 times that shown in the table, since all the phosphate for the 2- and 3-year-old stands was applied before the seeding of the crop. Finally, it should be mentioned that the 1956 seeding on Pembroke was the least satisfactory of all the seedings made on this soil.

The 3-year production record on the Mountview soil serves as a good illustration of the effect of moisture and general growing conditions in alfalfa production. The 1956 seeding on this soil came to a good stand but produced less than 2 tons of hay as a maximum in the dry year of 1957. (The yields of corn and cotton also were low in 1957, as shown in Table 3.) However, yields were much better the second year, and better still in the third year of production. This is just another illustration of the variation in yield to be expected with variation in rainfall and general growing conditions.

In Table 6 is a record of the 1957 wheat yields, followed by

Table 6.—Acre yields of wheat and alfalfa (first- and second-year crops) obtained on 3 soils following changes in fertilization made before seeding wheat in 1956.

Tmt. No.	Phosphate treatment	Pembroke			Mountview			Dickson		
		1957	1958	1959	1957	1958	1959	1957	1958	1959
		Wheat	Alfalfa hay	Alfalfa hay	Wheat	Alfalfa hay	Alfalfa hay	Wheat	Alfalfa hay	Alfalfa hay
		Bu.	Tons	Tons	Bu.	Tons	Tons	Bu.	Tons	Tons
1	No phosphate	23.1	0.82	1.49	23.9	1.45	1.89	18.0	0.77	0.65
2	CSP, 40	41.9	2.26	2.80	33.3	2.57	3.55	30.6	1.84	2.24
3	Residual phosphate ¹	40.8	2.06	2.40	35.4	2.25	2.96	28.1	1.50	1.81
4	CSP, 80 ²	44.2	2.46	2.76	36.4	2.64	3.64	28.1	1.71	2.28
5	OSP, 80 ²	..	..	..	36.3	2.64	3.59	...	...	...
L.S.D. (5%)		2.5	0.55	0.56	5.1	0.52	0.82	3.6	0.16	0.43

¹This treatment was CSP 80 on the wheat crop.

²These treatments received double the normal rate of potash on the wheat crop.

yields of first- and second-year alfalfa, which was seeded in 1957 following wheat harvest. Although a significant response to phosphate was obtained with every crop, there were no significant differences in yield among the four phosphate treatments, except with alfalfa on the Dickson soil. While the residual phosphate treatment on this soil produced hay yields much superior to those on the no-

phosphate treatment, they were significantly lower than they were where the phosphate applications were continued.

In Tables 7, 8, and 9 are more data showing successive yields of crops obtained following changes in fertilization made in the year indicated.

Wheat in 1958 and first-year alfalfa in 1959 on Pembroke soil showed significant decreases in yield on the residual phosphate treatment in the second and third year after the change in fertilization (Table 7). The alfalfa yield on the 80-pound P_2O_5 treatment was significantly higher than it was on the 40-pound treatment (3.53 tons vs. 2.95 tons). On Mountview soil the wheat yield showed a significant decline in 1958 on the residual phosphate treatment, but yields were essentially the same with the low and high rates of phosphate; also on the Dickson soil the alfalfa yield on the residual phosphate treatment was significantly lower than it was on the other phosphate treatments. The somewhat higher yield of corn on the residual treatment on Dickson soil in 1957 is probably of no significance in the light of the yields on the other phosphate treatments.

The data in Table 8 indicate significant declines in yields of cotton and wheat on Pembroke on the residual phosphate treatment. The same is true for cotton on Mountview in 1958 and for wheat on Dickson in 1959. These yield depressions occurred in the second and third years after the discontinuance of the phosphate applications. The double application of phosphate was not superior to the single application.

As shown in Table 9, the corn yield on the residual phosphate treatment on the Mountview soil in 1959 was significantly lower than the yields obtained where phosphate applications were continued. The double rate of phosphate was superior to the single rate on corn on the Pembroke soil in the same year. Both observations are of interest in that they represent the only two instances of significant first-year yield differences between the residual and the continued phosphate treatments.

In summary, considering all four crops on all three soils, the residual phosphate treatment, when compared with the continued 40-pound P_2O_5 treatment, showed no decline in yield in 1957—the year the phosphate application was discontinued. However, in the second year (1958) yields showed a 10% decline on the residual treatment, and in the third year (1959) a 16% decline. Crop yields showed little response to an increased rate of phosphate application

Table 7.—Acre yields of cotton, wheat, and alfalfa (first-year crop) obtained on 3 soils following changes in fertilization made beginning with the cotton crop in 1957.

Tmt. No.	Phosphate treatment	Pembroke			Mountview			Dickson			
		1957	1958	1959	1957	1958	1959	1957	1957	1958	1959
		Seed Cotton	Wheat	Alfalfa hay	Seed Cotton	Wheat	Alfalfa hay	Corn	Seed Cotton	Wheat	Alfalfa hay
		Lb.	Bu.	Tons	Lb.	Bu.	Tons	Bu.	Lb.	Bu.	Tons
1	No phosphate	1158	24.2	1.19	719	30.6	3.25	41.5	801	16.2	2.04
2	CSP, 40	1311	38.2	2.95	938	39.2	3.95	47.1	1002	27.4	4.18
3	Residual phosphate	1346	32.6	1.93	871	34.6	3.56	63.2	981	26.1	3.57
4	CSP, 80	1424	35.4	3.53	946	39.8	3.98	53.3	1032	27.7	4.94
5	OSP, 80	...	..	...	882	40.3	4.24	...	...	...	...
L.S.D. (5%)		N.S.	3.2	0.58	106	3.0	N.S.	12.8	176	3.9	0.44

Table 8.—Acre yields of corn, cotton, and wheat obtained on 3 soils following changes in fertilization made beginning with the corn crop in 1957.

Tmt. No.	Phosphate treatment	Pembroke			Mountview			Dickson		
		1957	1958	1959	1957	1958	1959	1958	1958	1959
		Corn	Seed Cotton	Wheat	Corn	Seed Cotton	Wheat	Corn	Seed Cotton	Wheat
		Bu.	Lb.	Bu.	Bu.	Lb.	Bu.	Bu.	Lb.	Bu.
1	No phosphate	36.7	1469	21.5	32.1	1178	24.7	30.5	1296	17.2
2	CSP, 40	59.3	2275	33.1	38.6	1716	39.3	58.3	1683	33.9
3	Residual phosphate	57.0	1781	25.1	42.8	1464	35.1	46.6	1689	28.2
4	CSP, 80	57.9	2208	36.7	38.7	1650	38.2	51.3	1641	32.9
5	OSP, 80	...	...	...	38.7	1736	38.0	...	...	...
L.S.D. (5%)		8.8	353	6.0	N.S.	113	4.8	17.2	268	4.9

Table 9.—Acre yields of corn and cotton obtained on 3 soils following changes in fertilization made beginning with the corn crop in 1958.

Tmt. No.	Phosphate treatment	Pembroke			Mountview			Dickson	
		1958	1959	1959	1958	1959	1959	1959	1959
		Corn	Seed Cotton	Corn ¹	Corn	Seed Cotton	Corn ¹	Corn	Seed Cotton
		Bu.	Lb.	Bu.	Bu.	Lb.	Bu.	Bu.	Lb.
1	No phosphate	73.5	1734	79.6	54.1	1494	69.4	36.8	1227
2	CSP, 40	98.6	2650	107.4	80.0	1667	92.6	63.9	1923
3	Residual phosphate	99.3	2428	101.8	82.9	1650	75.8	57.5	1742
4	CSP, 80	100.0	2666	116.6	83.8	1775	87.2	68.4	1971
5	OSP, 80	...	...	...	87.1	1894	90.2	...	...
L.S.D. (5%)		10.3	465	8.1	10.2	N.S.	12.5	14.1	229

¹Corn yields in 1959 reflect first-year effects of change in phosphate treatments.

(80 pounds of P_2O_5) until the third year. Crops on the Pembroke soil appeared to be a little more responsive to the higher rate of phosphate than those on the other two soils.

The Effect of Treatment on Soil-Test Values

Soil samples were collected in the fall of 1959 from each plot in each range at each of the four rotation experiments. Several cores were taken from each plot and composited. These samples were analyzed for pH, available phosphorus, and available potassium.³

Soil reaction (pH).—The range in soil reaction (pH) values on the various soils is shown in Table 10. Phosphate source and rate

Table 10.—Soil reaction (pH values) on samples collected in the fall of 1959. (The figures under pH values indicate the number of samples falling within the various limits.)

Soil type	pH values							
	5.5-5.6	5.7-5.8	5.9-6.0	6.1-6.2	6.3-6.4	6.5-6.6	6.7-6.8	6.9-7.0
Pembroke silt loam	0	0	0	6	46	37	7	0
Dickson silt loam	21	19	15	5	1	0	0	0
Mountview silt loam								
Freemon farm	0	1	14	30	27	8	3	1
Gower farm								
Range 1 ¹	4	10	9	4	0	0	0	0
Ranges 2-6 ²	2	2	6	11	15	43	42	14

¹Not re-limed.

²Re-limed in period 1957-1959.

did not appear to correlate with these values; therefore they are grouped for all treatments ranging from lowest to highest, with each group covering a range of two-tenths of a pH unit. Since the number of samples varied from one location to another, comparisons across soils should be made with this in mind.

These pH values are of interest from two standpoints. First, the wide range in values at any given location should be noted. This is an indication of the variation to be expected even when lime is "uniformly" applied. Second is the variation in degree of acidity from soil to soil and the change brought about by re-liming (Gower farm).

On the Pembroke soil most of the samples (86%) were in the range pH 6.3-6.6, while on the Dickson soil 90% of the samples were found in the range pH 5.5-6.0. Fifty-seven (68%) of the 84 samples on the Mountview soil on the Freemon farm were in the range pH

³The assistance of Joseph N. Matthews and his staff of the Soil Testing Laboratory at Nashville who made these determinations is gratefully acknowledged.

6.1-6.4. Mention has already been made that the initial pH of the soil at this site was 7.3. Thus, in 10 years the pH declined 1 unit. On the other Mountview soil (Gower farm) a considerable change in pH was brought about by re-liming, using dolomite at the rate of 2 tons per acre. This can be seen by comparing ranges 2-6 with range 1. Most of the samples on the re-limed ranges were in the range pH 6.5-6.8, while none of the samples tested above pH 6.2 where the second lime application was not made. As stated previously, lime was applied at the beginning of the experiment (1952) to all ranges at a rate of 3 tons per acre.

Available phosphate.—The available phosphate content, expressed as the element phosphorus (P), of the Pembroke, Dickson, and Mountview (Gower farm) soils is shown in Tables 11 to 13. This information for the Mountview soil on the Freemon farm is not shown because all plots of all treatments tested very high (VH) in phosphorus, due to a previous application of rock phosphate on this area. The rock phosphate treatments at the other three sites also tested very high. These high values do not mean that these soils were high in plant-available phosphorus, but that the soil-test method is not suitable in instances where rock phosphate has been applied. For example, a prediction of no response to phosphate on the Mountview soil on the Freemon farm would have been in error, since the data already presented show that all crops did respond to applications of the more readily "available" phosphates. Soils treated with rock phosphate continue to give these "false" very high values long after the application is made, as evidenced by the

Table 11.—Available phosphorus (P) in Pembroke silt loam as determined by soil test on samples taken in the fall of 1959. (The 1959 crop is indicated for each range.)

(All values except those of treatment 6 are averages of three plots.)

Tmt. No.	Phosphate treatment	Range 1 (1st-yr. alfalfa)	Range 2 (2nd-yr. alfalfa)	Range 3 (wheat)	Range 4 (cotton)	Range 5 (corn)	Range 6 (3rd-yr. alfalfa)
Pounds of P per acre							
1	No phosphate	12	15	11	10	14	10
2	CSP, 40	24	20	20	21	19	20
3	Residual P ¹	10	18	12	26	19	30
4	CSP, 80 ²	36	35	26	24	23	25
5	Rock + CSP	VH ³	VH ³	VH ³	VH ³	VH ³	VH ³
6	Rock	VH ³	VH ³	VH ³	VH ³	VH ³	VH ³

¹This treatment was CMP, 40 until change was made beginning in fall of 1956.

²This treatment was FTP, 40 until change was made beginning in fall of 1956.

³VH = very high, meaning that the amount was too high for quantitative measurement.

fact that on the Freemon farm the material had been applied 18 years before the soil test.

On the Pembroke soil the soil test on the unphosphated treatment indicated an average level of 12 pounds of P per acre. The level was raised to 21 pounds of P where CSP had been applied at an annual rate of 40 pounds of P_2O_5 per acre for the duration of the experiment, and was further raised to 28 pounds of P where the 40-pound P_2O_5 rate was doubled in the last 4 years. Where the annual application of 40 pounds of P_2O_5 was discontinued the last 3 years of the experiment (the residual P treatment), the phosphate level declined to an average value of 19 pounds of P per acre. On some ranges this decline was much greater than on others. (See ranges 1 and 3 in Table 11.) As presently calibrated, 12 pounds of available P would be rated "low" in phosphate, 19 and 21 pounds would be rated "medium," and 28 pounds would be rated "high."

The phosphate level on the Dickson soil, as indicated by soil test, was somewhat higher than that on the Pembroke. The unphosphated treatment showed an average value of 16 pounds of available P per acre. On the continued 40-pound- P_2O_5 treatment this level was raised to 33 pounds of P, and where the phosphate rate was doubled in the later years, the level was further raised to 44 pounds of P. Where the phosphate application was discontinued in the later years the phosphate content declined to a level of 24 pounds of P per acre. As presently calibrated 16 and 24 pounds of available P would be rated "medium," and 33 and 44 pounds would be rated "very high."

Table 12.—Available phosphorus (P) in Dickson silt loam as determined by soil test on samples taken in the fall of 1959. (The 1959 crop is indicated for each range.)

(All values except those of treatment 6 are averages of three plots.)

Tmt. No.	Phosphate treatment	Range 1 (wheat)	Range 2 (corn and cotton)	Range 3 (2nd-yr. alfalfa)	Range 4 (1st-yr. alfalfa)
		Pounds of P per acre			
1	No phosphate	17	18	15	15
2	CSP, 40	46	24	32	29
3	Residual P ¹	16	32	22	24
4	CSP, 80 ²	43	40	43	48
5	Rock + CSP	VH ³	VH ³	VH ³	VH ³
6	Rock	VH ³	VH ³	VH ³	VH ³

¹This treatment was CMP, 40 until change was made beginning in fall of 1956.

²This treatment was FTP, 40 until change was made beginning in fall of 1956.

³VH = very high, meaning that the amount was too high for quantitative measurement.

On the Mountview soil (Gower farm) the phosphate level on the unphosphated treatment was lowest of all sites, its average value being 5 pounds of available P per acre. On the treatment where CSP had been applied at an annual rate of 40 pounds of P_2O_5 per acre for 7 years the level was 12 pounds of P; however, where this phosphate had been applied at double this rate (80 pounds of P_2O_5) for the same length of time, the level was 27 pounds of P per acre. It is of interest that the second 40-pound increment of phosphate raised the final P level of the soil to a greater extent than did the first increment. This is not surprising, since the yield data show that most of the increase in crop production resulting from phosphate fertilization can be credited to the first 40-pound increment. (See Table 4.) A difference in degree of phosphorus fixation by the soil at the two rates of phosphate application is also a factor to be reckoned with. Phosphorus levels of the soil where CMP and FTP were applied agreed well with those where CSP was used.

Table 13.—Available phosphorus (P) in Mountview silt loam (Gower farm) as determined by soil test on samples taken in the fall of 1959. (The 1959 crop is indicated for each range.)

(All values are averages of three plots)

Tmt. No.	Phosphate treatment	Range 1 (3rd-yr. alfalfa)	Range 2 (2nd-yr. alfalfa)	Range 3 (1st-yr. alfalfa)	Range 4 (Corn)	Range 5 (cotton)	Range 6 (wheat)
Pounds of P per acre							
1	No phosphate	3	8	4	4	4	6
2	CSP, 40	6	12	12	10	11	19
3	CSP, 80	18	23	37	25	25	31
4	CMP, 40	7	10	13	8	12	14
5	CMP, 80	15	23	27	20	22	24
6	FTP, 40	9	17	15	12	14	24
7	FTP, 80	24	27	33	19	32	47
8	Rock + CSP	VH ¹	VH ¹	VH ¹	VH ¹	VH ¹	VH ¹
9	CSP, 80 (K_2SO_4)	23	26	40	20	28	32

¹VH = very high, meaning that the amount was too high for quantitative measurement.

Available potash.—The available potash levels, expressed as the element potassium (K), of each soil are presented in Tables 14 to 17. The variation in the potassium levels of the different soils is of interest. Potassium levels were highest in the well-drained Pembroke soil (Table 14) and lowest in the Mountview soil on the Free-mon farm (Table 16). As a field average, available potassium was 300 pounds per acre on the Pembroke as compared to 120 pounds on the Mountview. The average potassium level in the other Mount-

view soil (Gower farm) was 220 pounds per acre, and on the Dickson soil 170 pounds.

Of equal interest are the levels with the various phosphate treatments within a given soil. For example, available potassium on the unphosphated and Rock treatments on the Pembroke soil were

Table 14.—Available potassium (K) in Pembroke silt loam as determined by soil test on samples taken in the fall of 1959. (The 1959 crop is indicated for each range.)

(All values except those of treatment 6 are averages of three plots)

Tmt. No.	Phosphate treatment	Range 1 (1st-yr. alfalfa)	Range 2 (2nd-yr. alfalfa)	Range 3 (wheat)	Range 4 (cotton)	Range 5 (corn)	Range 6 (3rd-yr. alfalfa)
Pounds of K per acre							
1	No phosphate	370	300	350	300	390	340
2	CSP, 40	220	230	290	280	280	310
3	Residual P ¹	300	240	310	270	300	330
4	CSP, 80 ²	210	230	270	260	310	380
5	Rock + CSP	250	260	290	300	300	330
6	Rock	340	240	380	360	340	360

¹This treatment was CMP, 40 until change was made in 1957.

²This treatment was FTP, 40 until change was made in 1957.

much higher (average 340 pounds) than they were on the other phosphate treatments (average 280 pounds). The explanation for this is that since the rate of potash fertilization was the same regardless of phosphate treatment, and since crop yields were lower where no phosphate or Rock was applied, then crop uptake and removal were not so large. Consequently, a build-up in potassium would be expected.

This same situation can be observed in the Dickson soil and in the Mountview soil on the Gower farm. There was not much difference in the potassium levels among the various phosphate treatments in the Mountview soil on the Freemon farm. This is not too surprising because crop response to phosphate was least at this site and was not evident at all in the early years of the experiment.

It will also be observed that, in general, potassium values tend to be lowest on second-year stands of alfalfa. Alfalfa has a high potassium requirement and a considerable drain on the soil's potash supply occurs when the hay crops are removed. In preparing the land for alfalfa the potash fertilization was for a 2-year period. In those cases where the crop remained on the land for 3 years, the potash for the third year was applied as a topdressing in the spring of that year. Consequently, soil samples taken at the end of the

second year of production and before the spring topdressing should reflect this depletion.

The average value of 120 pounds of available potassium per acre in the Mountview soil on the Freemon farm is only about one-half that in the other Mountview soil (Gower farm), and could have limited alfalfa production. It should be remembered, however, that

Table 15.—Available potassium (K) in Dickson silt loam as determined by soil test on samples taken in the fall of 1959.

(The 1959 crop(s) is indicated for each range.)

(All values except those of treatment 6 are averages of three plots)

Tmt. No.	Phosphate treatment	Range 1 (wheat)	Range 2 (corn and cotton)	Range 3 (2nd-yr. alfalfa)	Range 4 (1st-yr. alfalfa)
Pounds of K per acre					
1	No phosphate	260	210	230	250
2	CSP, 40	180	160	100	140
3	Residual P ¹	200	160	120	170
4	CSP, 80 ²	170	160	110	140
5	Rock + CSP	180	170	150	160
6	Rock	160	170	190	190

¹This treatment was CMP, 40 until change was made in 1957.

²This treatment was FTP, 40 until change was made in 1957.

Table 16.—Available potassium (K) in Mountview silt loam (Freemon farm) as determined by soil test on samples taken in the fall of 1959. (The 1959 crop is indicated for each range.)

(All values are averages of three plots)

Tmt. No.	Phosphate treatment	Range 1 (1st-yr. alfalfa)	Range 2 (2nd-yr. alfalfa)	Range 3 (wheat)	Range 4 (cotton)	Range 5 (corn)	Range 6 (3rd-yr. alfalfa)
Pounds of K per acre							
1	No phosphate	120	130	130	140	150	120
2	CSP, 40	130	100	120	120	120	100
3	Residual P ¹	140	110	130	120	120	90
4	CSP, 80 ²	120	110	120	120	110	110
5	OSP, 80 ³	120	100	120	120	110	110

¹This treatment was CMP, 40 until change was made beginning in fall of 1956.

²This treatment was FTP, 40 until change was made beginning in fall of 1956.

³This treatment was OSP, 40 until change was made beginning in fall of 1956.

the annual rate of potash fertilization on the Gower farm was 75 pounds of K₂O on all crops, whereas on the Freemon farm the rate was 50 pounds on the corn, cotton, and wheat crops, and 75 pounds on the alfalfa crop. Moreover, alfalfa yields on the Freemon farm

exceeded those on the Gower farm. This could explain in part the higher potassium levels on the latter.

Soil-test phosphorus as correlated with crop response to applied phosphate.—It has been shown that the soils at the four experimental sites differ widely in soil test values. How can these values be correlated with crop response to applications of fertilizer? Except for the two rates of potash applied to the alfalfa and wheat

Table 17.—Available potassium (K) in Mountview silt loam (Gower farm) as determined by soil test on samples taken in the fall of 1959. (The 1959 crop is indicated for each range.)

(All values are averages of three plots)

Tmt. No.	Phosphate treatment	Range 1	Range 2	Range 3	Range 4	Range 5	Range 6
		(3rd-yr. alfalfa)	(2nd yr. alfalfa)	(1st-yr. alfalfa)	(corn)	(cotton)	(wheat)
		Available K per acre					
1	No phosphate	390	360	490	340	270	320
2	CSP, 40	210	160	230	170	210	340
3	CSP, 80	200	150	310	180	180	210
4	CMP, 40	220	150	210	170	180	250
5	CMP, 80	200	150	350	160	170	270
6	FTP, 40	240	180	210	170	190	250
7	FTP, 80	180	150	190	150	170	250
8	Rock + CSP	210	220	340	240	210	250
9	CSP, 80 (K_2SO_4)	190	140	220	150	190	230

seedlings in the fall of 1956, the only fertilizer element under study in these experiments was phosphorus. Therefore, the discussion of necessity must largely be limited to crop response to applied phosphate.

Phosphorus levels on the unphosphated plots were lowest (5 pounds P per acre) in the Mountview soil on the Gower farm, next lowest (12 pounds P per acre) in the Pembroke soil, and highest (16 pounds P per acre) in the Dickson soil. Therefore, it might be argued that the response to applied phosphate should be greatest on the Mountview, next greatest on the Pembroke, and least on the Dickson soil. Since the yield levels were different on these soils, a more valid approach would be to calculate the percentage response of the crops to applied phosphate at each location. When this is done it will be seen that the crops were most responsive on the Mountview soil, a $2\frac{1}{3}$ - to 6-fold increase (average 270%) in yield being obtained from an annual 40-pound P_2O_5 application of CSP.

The next most responsive soil was Dickson where the average increase in yield from the same phosphate application was 68%.

This was followed by the Pembroke soil where the increase was 55%. Thus, the Dickson and Pembroke soils are somewhat out of line in terms of P level and degree of response; however, their soil-test values are relatively close together and therefore little difference should be expected in the degree of response to applied phosphate. Had summer droughts not been so severe in the first half of this 10-year period, the crops on Dickson might have been more responsive. Moreover, it is possible that more of the phosphorus is "fixed," or rendered unavailable, in the Pembroke than in the Dickson soil.

The average increase in crop yield attributable to phosphate on the Mountview soil on the Freemon farm was 27%, but this cannot be related to the level of available phosphorus in the soil because it is complicated by a previous application of rock phosphate.

General Discussion

Rainfall conditions.—The general growing conditions, primarily rainfall, throughout the 10-year period these rotation experiments were in progress, have been briefly mentioned. While no rainfall records were kept at any of the rotation sites, a study of the rainfall recorded at the nearby town of Lawrenceburg during the period 1951-1956 revealed that total annual rainfall was less than normal in 4 of these 6 years. Of much more significance for summer crops was the amount of rain in the months of July, August, and September. The records showed that rainfall in July was less than normal 3 years out of the 6; in August, 5 years out of the 6; and in September, all 6 years.

A glance at the year-by-year yield record of the four crops in tables 1 to 4 will show that yields of corn, cotton, and alfalfa were considerably higher in the last half of the period than they were in the first half. This is particularly true for the last 2 years (1958 and 1959), when summer rainfall was more adequate. It is therefore difficult, if not impossible, to say how much of this improvement in yield can be attributed to rainfall and how much can be attributed to the cumulative effects of fertilization or of the rotation itself.

Wheat after corn versus wheat after cotton.—The wheat crop was seeded after cotton harvest in all rotations. However, since cotton and corn were planted in a split-plot arrangement in the rotation on the Dickson soil and the plots were harvested separately, data are available on wheat yields following the two crops. On the average, wheat yields were about 1 bushel higher after corn than

after cotton—about 4% more. In 4 of the 7 years they were significantly higher following corn, but in no instance did the difference exceed 5 bushels. The wheat data reported in Table 2 are average yields of the two areas.

Weed invasion.—Of interest from an ecological standpoint was the weed vegetation observed in the fall of 1959 on the ranges where wheat had been harvested earlier that year. Ordinarily these ranges are turned shortly after wheat harvest in June and fallowed to destroy weeds before seeding to alfalfa in late summer. This was not done in 1959 because the rotations were to be discontinued with the harvest of the 1959 corn and cotton crops. Following a somewhat rainy summer the predominant weed observed in September in the small grain stubble on the Pembroke soil was crabgrass (*Digitaria sanguinalis*); on the Dickson soil it was Spreading Witch grass (*Panicum dichotomiflorum*); and on the Mountview soil (Gower farm) it was a mixture of crabgrass and ragweed (*Ambrosia artemisiifolia*). On the latter soil, ragweed was present only on the phosphated plots; the unphosphated plots had a practically pure stand of crabgrass.

Performance of alfalfa with respect to age of stand.—Alfalfa yields varied widely from year to year. One interesting question is: Were these variations largely due to seasonal conditions or were they related more to age of stand? There were as many as 8 instances where yield records were available for a complete cycle of stand duration. On the average the yields improved with age of stand at all locations except on the Mountview soil on the Gower farm. As an average of 7 observations on the Mountview soil on the Freemon farm, the phosphated treatment (CSP, 40) produced 26% of its total yield on 1-year-old stands and 35% and 39% respectively on stands of 2 and 3 years of age. The improvement in yield with time would indicate a progressive increase in depth of root penetration or more favorable soil moisture conditions, or both. Certainly, it would not indicate a depletion of plant nutrients to a critical or limiting level. The degree of response to phosphate did decline, however, with age of stand, particularly on the Pembroke soil. On this soil the response to phosphate was 152% on first-year alfalfa and 76% and 60% respectively on second- and third-year stands.

Distribution of alfalfa production.—The frequency of cutting of alfalfa and the distribution of hay production are of some interest. Alfalfa in these rotations was never clipped over three times, and in dry years only twice. Since the performance of alfalfa on the Mountview soil on the Freemon farm was typical of that at the

other locations, this site is used as the example. At this location the average date of the first cutting of alfalfa was May 21, when 55% of the annual production was obtained. The average date of the second cutting was July 3 when 30% of the total hay crop was produced. The average date of the third cutting was August 16, when only 15% of the total annual production was realized. Only two cuttings were made in the years 1951, 1956, and 1957.

It is not uncommon for alfalfa on deep, level soils to be clipped four times in years of normal rainfall. Only three clippings a year in the present experiments indicate shallow rooting and periods of inadequate soil moisture. A root study made on alfalfa on the Mountview soil in 1956 revealed a maximum depth of rooting of only 30 inches, with 78% of the total root weight in the surface 6 inches of soil.

Fertilizer costs.—As stated at the outset these rotations were set up to determine the importance of phosphate in a fertilization program and to evaluate different sources of phosphate. Nitrogen and potash were not under study but were applied to all treatments, including the unphosphated check, at uniform rates which were thought to be adequate. The increase in crop yields attributable to phosphate has already been discussed and the results show that it was highly profitable on all crops at all four locations. A discussion of the total fertilizer bill for nitrogen, phosphate, and potash follows.

In the following calculations of fertilizer costs, ammonium nitrate (33.5% N) is figured at \$85 per ton, concentrated superphosphate (48% P_2O_5) at \$68, and muriate of potash (60% K_2O) at \$56. These are at or near current prices (1961). Since the fertilizer costs varied but little from one location to another, the costs for the various crops on the Pembroke soil will be used as the example. The amounts of the various plant nutrients applied and their costs per acre on the different crops are as follows:

CORN	Nitrogen (90 lb. of N)	=	\$11.43
	Phosphate (40 lb. of P_2O_5)	=	2.83
	Potash (50 lb. of K_2O)	=	2.33
	Total	=	\$16.59
COTTON AND WHEAT	Nitrogen (50 lb. of N)	=	\$ 6.35
	Phosphate (40 lb. of P_2O_5)	=	2.83
	Potash (50 lb. of K_2O)	=	2.33
	Total	=	\$11.51

ALFALFA	Nitrogen (30 lb. of N)	=	\$ 3.81
	Phosphate (120 lbs. of P_2O_5)	=	8.50
	Potash (150 lb. of K_2O)	=	7.00
	Total	=	<u>\$19.31</u>

The fertilizer cost on corn was reduced to \$5.16 per acre where nitrogen was omitted. In the case of alfalfa the cost is for a 3-year period, or, for the life of the stand.

The above costs are in terms of the price of the separate fertilizer materials. The cost of a mixed fertilizer applied in an amount equivalent to these rates of fertilization might be slightly higher.

Since farmers in general buy their fertilizers already mixed by the manufacturer, a more meaningful fertilizer cost can be arrived at by calculating it in terms of some complete fertilizer mixture plus the cost of the additional nitrogen required to bring this element up to the specified rate. Such calculations indicate that the total fertilizer costs for each crop would be about \$1 higher than those listed above.

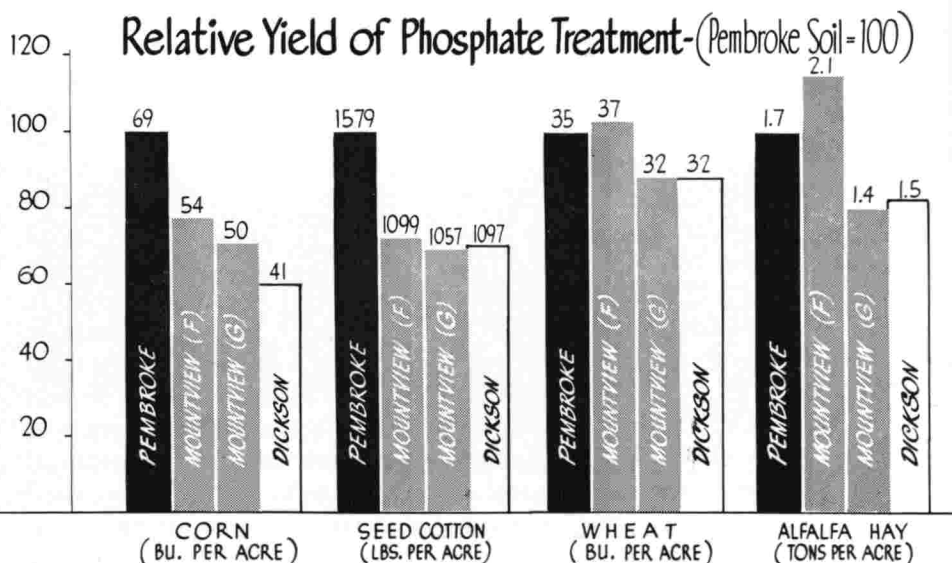


Figure 9.—Actual and relative average yields obtained with a complete nitrogen-phosphate-potash fertilizer on four crops at four locations.

Suitability of the soils for the different crops.—Since the same rotation was followed and the fertilization was essentially the same at all locations, it follows that the yields of the various crops over

as much as a 10-year period should reflect the suitability of these soils for these crops. This can be perhaps best illustrated by selecting the Pembroke soil as the standard and comparing its yield with the yields on the other soils. This has been done in Figure 9. In this comparison the average yield obtained on Pembroke with the complete fertilizer treatment (using concentrated superphosphate applied at a rate of 40 pounds of P_2O_5 per acre) is shown and is rated at 100. The actual yields are shown at the top of each bar. The Mountview soil labeled F represents the yields on the Freemon farm; that labeled G represents the yields on the Gower farm. Establishing the yields on Pembroke at 100 the relative yields on the other soils are as follows:

			Mountview (Freemon farm)	Mountview (Gower farm)*
	Pembroke	Dickson		

	Relative yield			
Corn	100	60	78	65
Seed Cotton	100	69	70	59
Wheat	100	90	105	84
Alfalfa hay	100	88	120	72

*Relative to yield on Pembroke for same period, or during 1953-1959.

In the above comparison it can readily be seen that the Dickson and Mountview soils were not as well adapted to the production of corn and cotton as was the Pembroke soil; yields of corn ranged from 60% to 78%, and cotton 59% to 70% of those obtained on Pembroke. In fact, corn and cotton yields on Pembroke in the dry years of 1951 and 1954 were about the same as the 10-year average yields on Dickson. The poor showing of these two crops on the Dickson and Mountview soils can be explained by the fact that these soils are somewhat shallow. The presence of a "hardpan" in the Dickson makes for restricted internal drainage, resulting in a wet soil in the winter and a droughty soil in the summer.

However, the yields of wheat on Dickson and Mountview soils were 84% to 105% of the yield on Pembroke. The wheat crop usually matures before summer droughts; therefore, these results would indicate that this crop—and presumably other winter crops—is capable of producing relatively better yields than corn or cotton on these and other soils of similar drainage and moisture characteristics.

Alfalfa yields on these four soils, both actual and relative, are a matter of some concern. The low yield on the Pembroke soil has already been discussed and was attributed to temporary ponding

of water in local depressions on a practically level site. However, the experimental area on the Mountview soil on the Freemon farm was also on a site equally level (Figure 10), and ponding of surface water was observed here also. But at this site there was no invasion by crabgrass, and while the alfalfa yields were not particularly noteworthy, they did exceed the yields on the Pembroke soil. The higher potassium and calcium status of the subsoil of Pembroke and

Figure 10.—The rotation on Mountview soil (Freemon farm) showing alfalfa crops in the foreground and cotton and corn (in the shock) in the background. Note level aspect of the site.



the higher yields of corn and cotton on this soil would lead one to expect higher yields of alfalfa also.

It might be argued that the explanation for the higher production of alfalfa on Mountview is to be found in the rock phosphate application, which was made several years before the present experiment was started. But the case for rock phosphate is weakened by the fact that this material not only gave a relatively poor initial performance in the other rotations, but showed no tendency to improve with the passing of time, even after the second application was made.

The most logical explanation for the higher yields of alfalfa on Mountview is in its high soil reaction, or pH. Experiments at other locations have shown that alfalfa does best on soils limed to pH values near or slightly above neutrality, or pH 7.0. Thus, it would appear that a pH level optimum for alfalfa might be detrimental to corn, in that this high level could bring about a zinc deficiency.

A thorough discussion of land use is beyond the province of this publication. But the relative suitability of the different soils for

the different crops, as brought out in these 10-year studies, does suggest certain changes in cropping practices on certain soils in order for them to compare more favorably with other soils.

When increases from 8 to 31 bushels of corn, from 160 to 650 pounds of seed cotton, from 9 to 23 bushels of wheat, and from $\frac{1}{2}$ to 1 ton of alfalfa hay are obtained on these four soils from an annual investment of less than \$3 in phosphate fertilizer, there can be no question about its profitableness. The profitableness of a larger application of phosphate (80 pounds of P_2O_5) is, however, subject to question. On the Gower farm this higher rate did result in a further increase over the lower rate of about 3.5 bushels of corn, 100 pounds of seed cotton, 2.5 bushels of wheat, and $\frac{1}{4}$ ton of alfalfa hay, but this soil was extremely low in available phosphorus. When the rate of phosphate application was doubled on the other three soils in the last 4 years of the experiment, little or no additional response was obtained from this higher rate, except possibly on the Pembroke soil.

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