THE EFFECTIVENESS OF ROCK PHOSPHATE AND SUPERPHOSPHATE ON YIELD AND COMPOSITION OF CROPS

Thesis for the Degree of Ph. D.

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THE EFFECTIVENESS OF ROCK PHOSPHATE AND SUPERPHOSPHATE ON YIELD AND COMPOSITION OF CROPS

By

John R. Guttay

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

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ABSTRACT

Research information up until 1950 on the relative effectiveness of rock phosphate and superphosphate was limited and difficult to interpolate over wide areas of the country. There was a definite need for a more uniform research program. Accordingly, in 1950, a project was organized for the north central region in which 8 member states (Michigan, Ohio, Indiana, Illinois, Minnesota, Iowa, Kansas, Nebraska) participated. This report summarized the results of the Michigan experiments.

Field experiments comparing an initial rock phosphate application of 320 pounds of P_2O_5 per acre to annual applications of superphosphate at 10 and 20 pounds of P_2O_5 per acre were carried out over an eight year period. Fried and Dean "A" values of the residual availability of the rock phosphate and superphosphate were calculated by radiochemical analyses of greenhouse grown plants.

Rock phosphate did not increase yields of corn even though significant increases were obtained with superphosphate. Soil tests made by the Bray "adsorbed phosphorus" (P_1) method, gave better estimates of the response of corn to phosphate in all cases, than did the Spurway "reserve."

The small grains exhibited some response to rock phosphate but less than to superphosphate and, generally, to a non-significant degree. The alfalfa-brome hay crops were more responsive than the other crops to rock phosphate, particularly to second-year hay, but the response was no greater than to superphosphate.

In terms of net increase in yield of oats per pound of applied P_2O_5,

superphosphate was, on the average of the four field experiments, 15 times more effective than rock phosphate in increasing yield. On first-year hay superphosphate was 12 times more and on second-year hay 8 times more effective than rock phosphate. In comparing the rock phosphate responsive crops in the four field experiments, superphosphate was 12 times more effective, on the average, than rock phosphate in increasing yield per pound of applied P_2O_5.

Fried and Dean "A" values of available phosphorus in the soil did not give consistent differences between the two sources of phosphorus and conclusions based on this value could not be drawn.

Little significant difference between phosphate treatments on phosphorus content of plants was observed.

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To all members of the Soil Science Department, without whose aid this investigation could not have been accomplished, this thesis is dedicated.

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INTRODUCTION

Phosphorus has been called the "master key to agriculture" (83) as well as the "bottleneck of the world's hunger" (92). Its importance in general farming is indicated by the fact that low crop production is due more often to the lack of phosphorus than to the lack of any other element (76). To illustrate the importance placed on phosphorus, the time devoted to its research should be considered. In the period from 1935-1950, 673 major articles were published in the United States alone on soil and fertilizer phosphorus (75).

Phosphorus is found in every living cell and is essential in both animal and plant nutrition. In plants, phosphorus is found in largest concentration in the seeds, whereas in animals along with calcium, it is found in the skeleton. Adequate amounts of available phosphorus in soils favor rapid plant growth and development and play both a direct and indirect role in their metabolism (67, 83).

The use of phosphorus containing materials for improving soil productivity is not new. In fact, the practice of using bones or fish for improving the productivity of soils has no exact record as to its origin. As early as 1653, an English writer mentioned the use of bones in British agriculture, but it was apparently not until the time of the American Revolution that the practice became fairly general. Even at this later date the reason for the beneficial effect of bones was not understood (83). About 1840 the first clear and intelligent exposition was written on the role of minerals in plant growth (97).

By about 1815 the English supply of bones was low and importations from other countries reached about 30,000 tons annually, showing that England was more alert to the need of phosphorus than other European countries. Liebig, in attempting to awaken the other European countries to the importance of bones wrote, "England is robbing all other countries of the condition of their fertility." (83). The problem of supply of phosphorus did not diminish, for at the turn of the 20th century Van Hise wrote, "The problem of the conservation of our phosphates is the most crucial, the most important, the most far reaching with reference to the future of this nation of any of the problems of conservation" (106).

The importance of phosphorus fertilization has not diminished in recent times. In a message to Congress on May 20, 1938, President Franklin D. Roosevelt said, "the phosphorus content of our land, following generations of cultivation has greatly diminished. It needs replenishing. I cannot overemphasize the importance of phosphorus not only to agriculture and soil conservation but also the physical health and economic security of the people of the nation. Many of our soil deposits are deficient in phosphorus, thus causing low yields and poor quality of crops and pastures" (91).

In 1867 deposits of rock phosphate were discovered in South Carolina and in the 1880's additional deposits were discovered in Florida (97). These discoveries gave American industry the opportunity to take the lead in the mining of rock phosphate. With the later discoveries of phosphate rock in Tennessee and in the western states it has been variously estimated that within the continental United States from about one-third to one-half of the known world reserves of phosphates are located (43, 44).

The principal types of phosphate deposits and mineral constituents are (58):

1. Igneous apatites	(fluorapatite)
2. Marine phosphorites	(carbonate-fluorapatite)
3. Residual phosphorites	(carbonate-fluorapatite)
4. River pebble	(carbonate-fluorapatite)
5. Phosphatized rock	(carbonate-hydroxyl-fluorapatite)
6. Guano	(carbonate-hydroxylapatite)

The most important types of deposits in the United States in respect to marketed production are the residual and marine phosphorites.

The residual phosphorites include the Florida land pebble (30-36% P_2O_5) and Tennessee brown rock phosphates (29-35% P_2O_5) which constitute the bulk of the rock phosphate marketed to date. These deposits were derived from phosphatic limestone formations where the more soluble carbonates have been weathered and leached out leaving the more insoluble phosphates. The Florida deposits, in addition, were subjected to marine erosion and rearrangement. The Tennessee deposits are much older than those in Florida being derived from rock of Ordovician age while the Florida deposits are from rock of Tertiary age (42, 43).

The Idaho and Montana deposits (27-37% P_2O_5) are marine-sedimentary in origin and chiefly of Permian age (84). The question as to the origin of these phosphate beds, termed the Phosphoria formation, is unanswered. Recent discoveries of nodular phosphate on the sea floor of southern California, however, suggest that these beds in Idaho could have been precipitated from sea waters by an increase in fluorine content of the water through volcanic activity.

The South Carolina phosphate reserves were depleted around 1920 but the Tennessee, Florida and far western states productions more than make up what was lost from the South Carolina depletion. It has been estimated that there is enough phosphate rock in Florida alone to last the United States, at the present rate of use, for 2,000 years (97).

Before the discovery of rock phosphate deposits, bones were the only known commercial source of phosphorus. Since bones supplied only a fraction of the need, the discovery of phosphate deposits was of great interest to agricultural workers. Early work, however, showed that rock phosphate was not as good a source of phosphorus as bone meal (90). The relatively inadequate supplies of bone meal, however, and the abundant and low cost supplies of rock phosphate soon resulted in rock phosphate being advocated in many areas as a main source of phosphorus for crop production.

While superphosphate had been available in the United States since 1868, its use as a fertilizer was limited mainly by its cost. Superphosphate is made by mixing approximately 1100 pounds of ground rock phosphate and 900 pounds of sulfuric acid for each ton of finished 16 percent superphosphate. These are mixed rapidly in cast-iron pans from which the mixture is poured while still in liquid form into bins where it hardens in a few minutes. After some days the superphosphate may be put through the mill and run back into the pile for further curing (38). This acidulation process converts the insoluble fluorapatite into the relatively soluble mono- and dicalcium phosphates. In 1920 the cost per pound of P_2O_5 as superphosphate was ten cents. Rock phosphate on the other hand cost only 2 cents per pound of P_2O_5. With this price differential five times as much rock phosphate as superphosphate could be applied to the land for the same price (63).

With technical advances the price of superphosphate began to diminish while, conversely, increases in cost of transportation and labor increased the cost of rock phosphate. By 1949, the price of superphosphate had decreased to 8 cents per pound of P_2O_5. The price of rock phosphate, however, increased to nearly 4 cents per pound of P_2O_5. With this price differential, the quality of the phosphorus in both materials became the governing factor in its purchase. The phosphorus in superphosphate has been regarded as available to plants while the phosphorus in rock phosphate has been regarded as generally unavailable without considerable time for reaction in the soil. Since there was a quality difference in the phosphorus compounds between the two fertilizer materials the question of relative effectiveness became a prime research problem. The question of whether 1 pound of superphosphate was equivalent to 2, 3 or more pounds of rock phosphate in supplying phosphorus for crop production needed to be answered. This research is intended, in part, to answer this question.

REVIEW OF LITERATURE

FACTORS AFFECTING ROCK PHOSPHATE USE

Many factors inherent in the material, in the soil, as well as time and crop govern crop response to rock phosphate.

Inherent Factors

Fineness

As would be expected the degree of fineness of rock phosphate affects its availability to plants to a certain extent. The same is true of the less soluble processed phosphates (78). Most of the rock phosphate sold for direct application to the soil is ground so that 90% or more will pass a 100 mesh sieve. Several investigators have studied the effect of fineness of rock phosphate on its availability to plants (17, 23, 26, 46, 81, 95). Their results show that in some cases finer particles than are found in the commercial product give a somewhat higher availability to plants. However, the increased availability did not seem to be great enough to justify grinding rock finer than the usual commercial product (90).

Fluorine Content

Investigations (39, 42) have shown that fluorine generally, is a part of the raw mineral phosphate in all deposits. In a study (6) of the response of sudangrass in the greenhouse to several raw phosphates of varying fluorine content, the natural phosphate containing the least fluorine produced the highest yield. Recent work (10), however, has shown no correlation between fluorine content of rock phosphates and their availability to plants. Chemical solubility has been suggested as a better measure of availability.

Source of Phosphate

The composition of commercial phosphate deposits varies considerably depending on the conditions under which they were laid down (39, 42). In greenhouse experiments different sources of rock phosphate have been compared on many soils and the availability of the phosphorus in the various sources have varied considerably (2, 16). The phosphate-bound carbonate content and citric acid solubility were the two measurements that showed the highest correlation with yields of alfalfa and relative effectiveness of different sources (21). In general, foreign sources which included Tunis, Morocco and Curacao Island have been superior to all of the domestic sources except that of South Carolina, now depleted (10).

The source of rock phosphate and fluorine content are apparently interrelated and the effect of the source on phosphate availability is probably due, in large part, to the inherent fluorine content characteristic for any particular source. The relatively available Curacao Island rock phosphates, for example, have low fluorine percentages (90).

"Colloidal phosphate" could be considered as a rock phosphate source. It is the by-product of the phosphate mining industry whereby the phosphate is washed into ponds and settled out from the hydraulic operations in the mining of rock phosphate. Experimental evidence comparing rock phosphate with colloidal phosphate generally shows no significant difference in the value of these materials when added in equivalent quantities (13, 15, 31, 65, 105). Colloidal phosphate may be considered finely divided rock phosphate diluted with colloidal clay material.

Soil Factors

Organic Matter

It has often been suggested that decomposing organic matter exerts a solvent action on raw phosphates and increases availability. Truog (103) and Bauer (8) studied the effect of fermenting cow manure and crop residues, respectively, on the availability of rock phosphate but the results failed to prove any solvent action. It has been suggested that the beneficial effect of adding organic matter, particularly manure, with rock phosphate comes from the extra phosphorus added in the organic matter rather than from a solvent action on the rock phosphate (11, 79).

Even though the solvent action of organic matter has not been proven, results continue to be reported in the literature as to the increase in the effectiveness of rock phosphate where crop residues were returned to the soil (68, 99) or where used with soils naturally high in organic matter content (81). In the greenhouse, each ton of green manure applied per acre produced sufficient carbonic acid to require an equivalent rate of 3000 pounds per acre of lime for neutralization. It is not likely that all of this carbonic acid would remain in the soil but it is probable that some of it would have opportunity to react with the slowly soluble phosphate in the soil (59). Russian workers have reported that mixtures of rock phosphate with peat or manure increases the availability of the phosphorus as indicated by the increase in amounts of water-soluble phosphorus and an increase in total ash and nitrogen content of the grain of crops treated with these mixtures (47, 48, 96). In addition, accelerated decomposition of the organic matter is credited to the rock phosphate addition.

Soil Reaction

Research has shown that liming may decrease the availability or efficiency of rock phosphate (3, 7, 23, 45, 69, 89, 95, 104, 107, 117). Numerous experiments have shown that rock phosphate is of little or no value when applied to the calcareous soils of the west (37, 55, 85, 102, 109, 116). DeTurk (27) states that free calcium carbonate may retard the intake of phosphorus from rock phosphate by plants which are not "strong feeders". It has been shown, however, that the effect of lime is less when applied well in advance of rock phosphate (1).

Smith (99) in attempting to determine the cause of the differential response to rock phosphate by crops grown on two Illinois soils concluded that the surface pH had no effect on the response. At pH 6.6, however, the availability of rock phosphate was found to be actually reduced on incubation (46). Also it has been found that adding sulphur to a soil which had been over-limed released sufficient available phosphorus from rock phosphate for satisfactory growth of oats and clover at pH 6.5 (77). Other experiments (34), using tracer techniques, showed that with rock phosphate the higher the soil pH the lower the relative amounts of fertilizer phosphorus to soil phosphorus absorbed by the plant.

The practice of not liming in order to utilize rock phosphate fertilizer has been shown to be in error. Lime plus superphosphate has produced better yields of crops than rock phosphate alone (49, 81, 88).

Incubation Period

The availability of rock phosphate on an acid Virginia soil was increased by applying the material well in advance of the crop (11 months) for which it was intended (71). However, the amount of phosphorus extractable on soils treated with rock phosphate in Texas showed a decreased availability with time of contact (20). This indicates that soil types vary in their inherent soil characteristics with respect to reactions with rock phosphate depending on whether the reaction is going toward release of phosphorus or towards fixation. Certainly incubation such as in composting would increase the availability of phosphorus in rock phosphate (30).

Placement

Little placement work has been done with rock phosphate. The literature refers largely to broadcast methods or plow-down. Ohio data (81) on the banding of rock phosphate for corn and oats compared to banded superphosphate show very poor response by the crops to rock phosphate. Similar results are reported on the banding of rock phosphate for wheat in Nebraska (112).

Recent research (56) indicates that the less soluble phosphates are more effective when mixed intimately with the soil. Conversely, the more soluble phosphates are more effective when banded. Further, the finer material is more effective when banded and the coarser material is more effective when intimately mixed with the soil. In the case of rock phosphate, these data would support the idea that rock phosphate is at its most effective placement when intimately mixed with the soil. The data would further substantiate the fact that superphosphate, particularly the fine material, is at a decided disadvantage when mixed intimately with the soil.

Crop Factors

The utilization of the phosphorus in rock phosphate by various plants is an important consideration in the interpretation of results. Many workers (5, 8, 14, 25, 27, 28, 36, 64, 74, 80, 81, 104) have shown that plant species differ in this respect. In general, it can be said that most of the cereals are "poor feeders", whereas buckwheat and some legumes such as sweet clover, alfalfa and red clover are "strong feeders". It is fairly certain that satisfactory results from rock phosphate will not be obtained unless crops that are "strong feeders" are used in the rotation. Truog (104) suggested that plants that require relatively high amounts of calcium are more likely to be able to utilize slightly soluble phosphates. The removing of the slightly soluble calcium from an equilibrium condition by plants tends to drive the reaction to completion, releasing phosphorus.

Relative Effectiveness of Rock Phosphate and Superphosphate

Work with rock phosphate at the Ohio Experiment Station, over a 35 year period, where rock phosphate was applied at a rate equal to twice as much P_2O_5 as that applied in superphosphate on an acid soil (pH 5.0) showed that rock phosphate was consistently less effective than the superphosphate (95). In a report from Alabama (31) rock phosphate applied at twice the P_2O_5 rate of superphosphate resulted in half the yield increase attributable to superphosphate. Research in Arkansas (61) comparing equal money values of rock phosphate and superphosphate, which from 1952-1955 amounted to two and a half times as much P_2O_5 as rock phosphate as in the form of superphosphate, showed crop yields similar with the two materials. In Tennessee (57), however, at these same levels of application, yields with the rock phosphate were only one third that from superphosphate. In Ohio, rock phosphate applied to corn at three times the rate of superphosphate (in lime of P_2O_5), from 1915 to 1933, was considerably less effective than the superphosphate (95). In Kentucky (74) three and a half to four times as much rock phosphate P_2O_5 as superphosphate P_2O_5 was needed to give equal yield.

Hopkins (41) showed that rock phosphate generally produced crop yields somewhat higher than did the superphosphate when the P_2O_5 rate was 4 to 1. On one field, the superphosphate was slightly better than the rock. The response of the crops to phosphorus in all cases, however, was small and actually unprofitable. Other experiments from Illinois (9) indicate that rock phosphate was roughly equivalent to superphosphate at four times the P_2O_5 rate under both limed and unlimed conditions.

In 1904, at the Indiana Agricultural Experiment Station, 82 field tests were laid out where finely ground rock phosphate was compared with superphosphate at the 4 to 1 rate. In these tests phosphate rock showed a profit but to a much smaller degree than did superphosphate (87, 114). In a Virginia report (29) of greenhouse experiments with vegetable crops, rock phosphate, at four times the P_2O_5 rate as superphosphate, was in most cases less effective than the superphosphate. In Alabama (31) rock phosphate at 4 times the P_2O_5 level of superphosphate did not equal the superphosphate in crop yield.

In Nebraska in 1950, five times as much P_2O_5 as rock phosphate did not produce as great a wheat yield as did superphosphate (112). A report from Kansas (98) showed that rock phosphate applied at approximately six times the P_2O_5 rate of superphosphate resulted in similar crop yields. It is important to note here that when rock phosphate is applied at six or more times the P_2O_5 rate of superphosphate the amount of immediately available phosphorus becomes substantial.

In a series of field experiments in Minnesota where rock phosphate had been applied, at seven and ten times the rate of P_2O_5 as superphosphate, the superphosphate was generally superior to the rock phosphate even when a much greater amount of rock phosphate was applied (93). There were a few cases in this experiment where better increases were obtained with rock phosphate and there were some instances where superphosphate was strikingly better than the rock phosphate.

As little as 18 pounds of P_2O_5 as superphosphate drilled with the wheat at seeding time in Indiana, produced about the same increase as sixteen times that amount applied broadcast as rock phosphate (73).

In a greenhouse experiment, reported in 1957 (33), rock phosphate and superphosphate were applied at equal rates of citrate soluble phosphorus, which amounted to twenty five times as much rock phosphate P_2O_5 as that applied as superphosphate. Oats did better on the superphosphate while alfalfa did better on rock phosphate.

In Virginia (70), in 1957, on a soil which had been the most responsive to rock phosphate it required 600 pounds of rock phosphate P_2O_5 to produce as much increase in corn yield as was obtained from 20 pounds applied as superphosphate. Yield increases by 35 pounds of P_2O_5 as superphosphate on wheat required seventeen times as much P_2O_5 as the rock phosphate and 56 pounds of P_2O_5 as superphosphate on red clover required eleven times as much rock phosphate. On a soil which had been least responsive to rock phosphate thirty times as much P_2O_5 as rock phosphate was approximately equivalent to 20 pounds of P_2O_5 as superphosphate for wheat. On an intermediately responsive soil fifteen times as much P_2O_5 as rock phosphate was approximately equivalent to 40 pounds of superphosphate P_2O_5 for alfalfa.

A report on regional rock phosphate studies in Indiana (4) showed that 10 pounds of P_2O_5 as superphosphate in the row produced a yield equivalent to thirty-two and sixty-four times as much P_2O_5 as rock phosphate broadcast. This occurred with corn, soybeans and hay. With wheat, rock phosphate did not produce significant increases in yield at any rate, while superphosphate produced a substantial increase in yield at 30 pounds of P_2O_5 applied in the row.

Residual Effects

The advocates of the use of rock phosphate as a fertilizing material, while conceding that superphosphate may be more soluble and more quickly available, profess that the greatest benefits of rock phosphate come in its residual effect (31, 51, 53, 54). Data from Illinois (52)show that over a 15 year period, rock phosphate (450 pounds P_2O_5) had a greater residual effect and produced a greater gross return in crops than a money equivalent (1935 prices) of superphosphate (160 pounds P_2O_5). In Kentucky (110) there was no decline in yield on plots treated with rock phosphate (752 pounds P_2O_5) in 16 years while with superphosphate (160 pounds P_2O_5) yields declined. A 1950 report from the U. S. S. R. (50) states that the phosphorus availability of rock phosphate continues for a long period of years (25 years in experimental work). A publication from Arkansas (60), in 1954, reported the results of a greenhouse study in which 32% rock phosphate and 18% superphosphate were applied in equal amounts every four years until a total of 4000 pounds had been applied over 32 years. Sodium bicarbonate extraction of phosphorus from the soil treated with rock phosphate showed over three times as much phosphorus as where superphosphate was applied. Further, the values determined by the Fried and Dean method (35) showed that the soils treated with rock phosphate had a greater availability of phosphorus than where superphosphate was used. However, none of the crops grown, whether buckwheat, oats, or alfalfa showed any greater growth from the applied rock phosphate than from the superphosphate, yet all gave significant yield increases.

In 1957 in a report from Alabama (32) of a field experiment where various sources of phosphorus were applied, including rock phosphate and superphosphate, the residual effects of all phosphates after 20 years was in direct proportion to the amount applied.

A summary of European work (24) on phosphate carriers states that any complete attempt to differentiate the effects of contrasted phosphates on different kinds of soils should take into account 1., pH, 2., base status, 3., humus content and 4., available soil phosphorus. Swedish work on soils with pH less than 6.0 has shown that superphosphate gives the best yields in the first year but rock phosphate has a greater residual effect. On less acid or neutral soils, (pH greater than 6.0) both immediate and residual effects of superphosphate are greater than rock phosphate. Rock phosphate on these soils was considered of little value.

In summarizing the views held in Sweden and the United Kingdom on the use of phosphorus fertilizer the report states, "although insoluble fertilizers may give higher residual effects than superphosphate on very acid soils this fact may not be very important since such soils should be limed before they receive dressings of phosphate. It is better to improve the phosphorus status of acid soils by liming and then using soluble phosphorus than by omitting liming in order to make use of insoluble fertilizers". Workers in Norway also consider that insoluble phosphates may have advantages over superphosphates on very acid soils but such soils should be limed.

Unpublished data from Texas (18) shows considerably more residual effect from rock than superphosphate but a considerable superiority for frequent small applications of superphosphate. Other data (111) indicated that an annual application of superphosphate was superior to single large applications of rock phosphate in uniform and high production of forage and protein. In this respect, superphosphate has been shown to be more effective in small annual applications than when applied in a single large application (22). Frequent small applications of rock phosphate such as at 100 pounds per acre of P_2O_5 annually resulted in yields and residual effect no greater than that of the nonphosphated plots (19). In the plots receiving superphosphate, P^{32} absorption data indicated that there was sometimes twice as much available phosphorus as in soils which had received rock phosphate or were not phosphated.

In a Virginia (72) report the availability of residual phosphorus from long time superphosphate application was four times that of rock phosphate. These data are based on annual applications of rock phosphate and superphosphate at an equivalent total P_2O_5 basis totaling 2800 pounds of P_2O_5 over 40 years. Approximately 3/4 of the phosphorus applied over this period from either source was present in the soil as residual phosphorus. This quantity nearly doubled the original total phosphorus content of the soil. A Minnesota (12) study of the residual effects of 3300 pounds of rock phosphate and 768 pounds of superphosphate over a period of 40 years showed that 9 years after the application of the two phosphates and manure had ceased, superphosphate was much superior to rock phosphate in its ability to supply residual phosphorus. Similar results were reported in Indiana (88). Many other reports on the residual value of superphosphate have also been published (82, 94, 101, 108, 115).

EXPERIMENTAL METHODS AND RESULTS

In 1950, a project was organized to study the relative effectiveness of rock and superphosphate in the north central region in which 8 member states (Michigan, Ohio, Indiana, Illinois, Minnesota, Iowa, Kansas, Nebraska) participated. This report summarizes the results of the Michigan experiments.

Field Experiments

Experimental Procedure

Six treatments were utilized in the Michigan experiment:

1. No phosphate
2. Superphosphate at 10 pounds of P_2O_5 per acre per year
3. Superphosphate at 20 pounds of P_2O_5 per acre per year
4. Rock phosphate at 320 pounds of P_2O_5 per acre per 8 years
5. Rock phosphate at 320 pounds of P_2O_5 plus superphosphate at 10 pounds of P_2O_5 per acre per year
6. Rock phosphate at 320 pounds of P_2O_5 plus superphosphate at 20 pounds of P_2O_5 per acre per year

Treatments 1, 2, 4 and 5 were common throughout the region and 3 and 6 were optional. The phosphate treatments were applied in a manner recommended for that particular material. The superphosphate was banded at planting time for each crop and the rock phosphate broadcast in a single application (960 pounds per acre) at the beginning of the experiment. Research data have shown (56) that as the water solubility of the phosphorus source increases greater benefit to crop growth is afforded by band placement of the phosphorus and conversely as the water solubility decreases greater benefit occurs with intimate mixing with the soil. In the case of this experiment, therefore, where superphosphate was banded

(85% of phosphorus water soluble) and rock phosphate (no water soluble phosphorus) was mixed with the soil, both sources were compared at their optimum. The rock phosphate used in the region was from the same source, Florida, and of the same specifications, 33% P_2O_5, 85% through a 200 mesh sieve.

Four locations were chosen in Michigan three of which had an additional split treatment of liming (Kalamazoo, Genesee, Grand Traverse Counties). The cropping system on these three locations consisted of two years of alfalfa-brome hay, followed by corn and spring oats. On the fourth location (Iosco County) the cropping sequence was two years of alfalfa hay followed by corn and winter wheat.

The experimental areas were divided into 4 fields so that each crop appeared each year. The statistical design of the Kalamazoo, Genesee and Grand Traverse experiments was a split-plot with liming being the main plot and phosphorus source the sub-plots. The sub-plot size at the Genesee location was 28 x 50 feet and at the other locations 21 x 50 feet. In the Iosco County experiments a randomized block design was used with plots 21 x 50 feet in size. The treatments at all four locations were replicated four times.

Nitrogen and potash were top-dressed prior to planting each crop to insure an adequate supply of these nutrients (60 pounds of N, 60 pounds of K_2O for corn, and 30 pounds N, 60 pounds K_2O for the small grains). The land was fitted with minimum tillage and crops of recommended varieties were sown by conventional means.

Kalamazoo County

The experiments in Kalamazoo County were located on the John Campbell farm, 4 miles north and east of the city of Kalamazoo in section 4, township 2 south, range 10 west.

The farming in this area of the state is largely comprised of dairying with the raising of hogs, beef cattle, poultry and sheep of importance on certain farms. The major factors influencing the farming of the area are the generally lighter soils, the relatively long growing season and the local markets of Battle Creek and Kalamazoo (40).

The growing season in this area ranges from 150 to 170 days. The last frost in the spring occurs between May 1 and 10 and the first in the fall between October 1 and 10. The elevation varies from 800 to 1000 feet above sea level with the topography ranging from level to rolling. Many of the level outwash plains are strongly pitted (40).

The soils to plow depth are dominantly light colored sandy loams, light loams and loamy sands easily tilled, moderately productive and responsive to manure and commercial fertilizers. They are not excessively droughty, but the lack of moisture-holding capacity, combined with the natural low fertility, is probably the greatest limiting factor in crop yields. The soils are generally acid in the surface and sub-soil layers and are low in organic matter content. Liming is usually required for satisfactory stands of alfalfa (113). The 1947-1951 average per acre yields of field crops in Kalamazoo County were as follows: corn, 34 bushels; oats, 37 bushels; wheat 24 bushels; hay 1.4 tons (40).

The soils of the experimental area were level and very uniform, being predominantly Kalamazoo sandy loam. Approximately one quarter of the area was slightly heavier in texture and was Kalamazoo loam.

Ground limestone at a rate of 1½ tons per acre was applied to appropriate blocks in 1950 so that one-half of the area was limed. This liming, however, was totally inadequate for the acid conditions prevailing (pH 5.1-5.5) and as a result this lime was virtually ineffective. (The soil reaction in 1956 of limed plots was pH 5.4-5.8). The lime requirement for the original pH level on this soil was more nearly 3½ to 4½ tons per acre (86).

Of the six cropping years (1951-1956) at this location, three years, 1953, 1954, 1955 were characterized by late summer droughts. Two years, 1951 and 1956 had adequate precipitation but were relatively cool. Only in 1952 did the climatic factors combine to give a good cropping year.

Corn. The corn yields were very good in 1952, fair in 1951 and 1956 and poor in 1954 and 1955. The crop in 1953 did not receive a single rain and was a complete failure.

During the planting of the 1955 crop, a break-down occurred in the midst of the planting operation. The sixteen plots which did not receive superphosphate and three of the plots receiving superphosphate had been planted prior to the time the mounted planter broke loose from the tractor. The planting of the remaining twenty-nine plots was completed after repairs were made. These plots, planted after repairs, had a very poor stand (as measured in July) in relation to those planted previous to the break-down. Since yields were related to stand ($r=0.760^{**}$) and stand related to some unknown difficulty the 1955 yields are not included in the corn yield summary given in Table 1.

The effects of lime on corn yields were non-significant whether considered yearly or as an average over the entire experiment. Since the effects of lime were not significant the yields presented in Table 1 are treatment means over lime levels.

Treatment means were significantly different at the 5% level in 1954. However, little importance can be attached to this result. The apparent statistical signifcance can be accounted for by the fact that corn without phosphate produced lower yields where limed than where unlimed and with rock phosphate produced higher yields where limed than where unlimed. This seemingly incongruous interaction was of sufficient magnitude to affect the analysis of variance and it should not be misconstrued as a phosphate response.

The analysis of variance presented in Table 1, for the corn data over the four years 1951, 1952, 1954 and 1956 does not show significant treatment effects. A response to phosphorus by corn at this location would be expected in considering the soil tests by the Spurway "reserve" test, as presented in Table 2. The plots which did not receive phosphate or those treated with superphosphate alone had low (< 50 pounds per/acre (66)) tests for phosphorus. Corn on these plots should have exhibited a phosphate response but the plots treated with rock phosphate had high (> 50 pounds per acre) tests and little phosphate response would be expected here on the basis of the tests alone.

When tests of these same samples were made using the Bray adsorbed phosphorus (P_1) test, however, all tests were very high (> 35 pounds per acre) and little response to phosphorus would be expected. In this case then, the Bray P_1 tests gave a better estimate of crop response to phosphorus fertilizer.

The percent phosphorus in both green tissue and grain of the 1956 crop are presented in Table 3. The third leaf below the ear was stripped

TABLE 1. YIELD OF CORN AT THE KALAMAZOO COUNTY LOCATION.

Treatment(per acre)	Bushels per Acre 1951	1952	1954	1956	Ave.
No phosphate fertilizer	51.1	80.7	31.8	61.6	51.4
10 lbs. P_2O_5(0-20-0)per year	57.6	77.0	42.4	62.1	50.7
20 lbs. P_2O_5(0-20-0)per year	59.5	75.2	45.0	60.7	51.9
320 lbs. P_2O_5(rock)1951	56.7	74.2	40.2	62.2	53.2
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	55.1	73.0	39.6	57.9	49.4
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	56.6	81.3	40.4	62.8	52.5
L.S.D.(5% level)	n.s.	n.s.	7.6	n.s.	n.s.

Analysis of Variance:

Source of Variation	Degrees of freedom	Mean square	"F" test
Total	191		
Replicates	12	321.43	2.31 n.s.
Years(Y)	3	11,164.75	80.33**
Lime(L)	1	17.52	0.12 n.s.
L x Y	3	461.80	3.32 n.s.
Error(a)	12	138.98	
Treatments(T)	5	105.99	1.91 n.s.
T x L	5	44.95	0.81 n.s.
T x Y	15	78.10	1.41 n.s.
T x Y x L	15	90.23	1.63 n.s.
Error(b)	120	55.21	

TABLE 2. AVAILABLE SOIL PHOSPHORUS+ PRIOR TO CORN PLANTING AT THE KALAMAZOO COUNTY LOCATION

Treatment(per acre)	1952 S	1954 S	1954 P_1	1956 S	1956 P_1	Ave. S	Ave. P_1
	Pounds per Acre						
No phosphate fertilizer	8	16	65	27	66	18	65
10 lbs. P_2O_5(0-20-0)per year	11	15	71	33	73	22	72
20 lbs. P_2O_5(0-20-0)per year	8	15	62	38	81	23	71
320 lbs. P_2O_5(rock)1951	53	57	68	69	71	61	69
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	63	88	76	75	77	70	76
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	39	111	68	91	100	65	83
L.S.D.(5% level)	18	--	n.s.	13	17	11	10

+ S = Spurway reserve test (Extract is 0.13N HCl, 1:4 soil:extract ratio)

P_1 = Bray adsorbed phosphorus test (Extract is 0.025N HCl + 0.03N NH_4F, 1:7 soil:extract ratio) off and composited from several representative plants in each plot when the corn tasseled. The grain analysis was made on a representative sample of the harvested yield. The plant samples were wet-ashed, taken up in 0.1N HCl and the phosphorus content determined colorimetrically using the ammonium molybdate method.

Little relationship was observed between the phosphorus content of the plant samples and the phosphorus applied to the soil. However, there was more phosphorus in leaf samples from the phosphate treatments than from those without phosphate and less phosphorus in the grain where phosphate had been applied than where without phosphate.

Oats. The dry weather which seriously affected corn yields occurred at a less critical time in respect to oat development and yields were therefore, less drastically affected. The oat yields of 1953, when the corn crop failed, however, were rather poor. Liming increased yields significantly in 1956 but in the other 5 years did not have significant effects so the data presented in Table 4 are treatment means over lime levels.

In the four years of significant treatment effects the annual 20 pounds per acre rate of P_2O_5 as superphosphate produced higher oat yields than did the 1951 application of 320 pounds per acre of P_2O_5 as rock phosphate. In three of the years the 10 pound per acre of P_2O_5 as superphosphate produced higher yields than did the rock phosphate and lower yields in one year.

The average effect shows a significant yield response to all phosphates for the six years. The only significant difference between phosphate treatments occurred with the significantly higher yield produced with the 20 pound rate of P_2O_5 as superphosphate than that obtained with rock phosphate.

TABLE 3. TOTAL PHOSPHORUS IN THE GREEN TISSUE AND HARVESTED GRAIN OF THE 1956 CORN CROP. KALAMAZOO COUNTY

Treatment(per acre)	Percent Phosphorus Leaves	Percent Phosphorus Grain
No phosphate fertilizer	0.209	0.529
10 lbs. P_2O_5(0-20-0)per year	0.325	0.503
20 lbs. P_2O_5(0-20-0)per year	0.258	0.443
320 lbs. P_2O_5(rock)1951	0.293	0.479
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	0.214	0.465
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	0.279	0.494
L.S.D.(5% level)	n.s.	n.s.

TABLE 4. YIELD OF OATS AT THE KALAMAZOO COUNTY LOCATION

Treatment(per acre)	Bushels per Acre						
	1951	1952	1953	1954	1955	1956	Ave.
No phosphate fertilizer	43.7	46.3	30.1	39.5	46.6	43.2	41.6
10 lbs. P_2O_5(0-20-0)per year	42.9	54.8	29.1	49.3	48.9	46.5	45.2
20 lbs. P_2O_5(0-20-0)per year	44.1	55.7	27.7	50.9	54.1	51.5	47.3
320 lbs. P_2O_5(rock)1951	40.2	52.5	30.2	45.6	47.0	50.5	44.3
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	38.2	55.7	28.8	51.4	50.8	49.3	45.7
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	42.5	56.0	28.7	51.4	49.1	48.2	46.0
L.S.D.(5% level)	n.s.	5.5	n.s.	4.5	4.6	4.9	2.2

Analysis of Variance:

Source of Variation	Degrees of freedom	Mean square	"F" test
Total	287		
Replicates	18	78.06	0.48 n.s.
Years(Y)	5	3,574.19	21.75**
Lime(L)	1	27.26	0.17 n.s.
L x Y	5	55.95	0.34 n.s.
Error(a)	18	164.30	
Treatments(T)	5	184.64	6.14**
T x L	5	35.55	1.18 n.s.
T x Y	25	58.25	1.94**
T x Y x L	25	29.85	0.99 n.s.
Error(b)	180	30.06	

Little, if any, benefit occurred in the rock phosphate plus superphosphate treatments beyond that achieved with superphosphate alone.

The net increase in yield of oats produced by phosphate fertilization over the entire six year period and the total amount of phosphate applied during this period are presented in Table 5. From these values the effectiveness value or the bushels increase per pound of P_2O_5 applied can be calculated. If this value can be assumed real then a relative effectiveness value can be determined between treatments. The lower rate of superphosphate addition resulted in a net yield increase of 22.1 bushels per acre with 60 pounds of P_2O_5 added over the 6 years or an effectiveness value of 0.37 bushels increase per pound of P_2O_5 applied. The rock phosphate treatment yielded only 16.6 bushels per acre net increase over this period or 0.05 bushels per pound of P_2O_5 added. At the productivity level attained with the lower superphosphate rate, therefore, the superphosphate could be evaluated as having a relative effectiveness seven times that of the rock phosphate.

The higher rate of superphosphate resulted in a net increase of 34.6 bushels or an increase of 0.29 bushels per pound of P_2O_5. This value indicates that superphosphate had a relative effectiveness in terms of P_2O_5 six times that of the rock phosphate at this yield level.

The combination treatments of rock phosphate plus superphosphate, as mentioned previously, had little, if any, affect on yield beyond that of superphosphate alone.

Representative portions of the 1954, 1955 and 1956 oat crops, sampled at heading time, were analyzed for total phosphorus. These data are presented in Table 6. Liming did not significantly affect phosphorus content

TABLE 5. NET INCREASE IN YIELD OF OATS IN 6 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE KALAMAZOO COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Bushels Increase in Yield	Effectiveness Values Bu/lb P_2O_5	Relative
10 lbs. P_2O_5(0-20-0)per year	60	22.1	0.37	7
20 lbs. P_2O_5(0-20-0)per year	120	34.6	0.29	6
320 lbs. P_2O_5(rock)1951	320	16.6	0.05	1
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	380	24.8	0.07	1
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	440	26.5	0.06	1

TABLE 6. TOTAL PHOSPHORUS IN OATS SAMPLED AT HEADING TIME AT THE KALAMAZOO COUNTY LOCATION

Treatment(per acre)	Percent Phosphorus 1954	1955	1956	Ave.
No phosphate fertilizer	0.300	0.273	0.227	0.267
10 lbs. P_2O_5(0-20-0)per year	0.299	0.269	0.226	0.265
20 lbs. P_2O_5(0-20-0)per year	0.326	0.260	0.230	0.272
320 lbs. P_2O_5(rock)1951	0.314	0.255	0.249	0.273
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	0.320	0.266	0.253	0.280
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	0.320	0.286	0.268	0.291
L.S.D.(5% level)	n.s.	n.s.	n.s.	n.s.

nor were there significant lime interactions. These data, therefore, are treatment means over lime levels. Statistically, the differences between treatment means were non-significant, however, there was a trend toward higher phosphorus content as the rate of P_2O_5 applied increased.

Hay. Alfalfa-brome yields were generally poor, particularly the second cuttings which were seriously affected by the late summer droughts. Second cuttings were not harvested in 1954, 1955 and 1956 and very poor in the two previous years of 1952 and 1953. In 1954 and 1955 the first year hay crops were not harvestable due to dry conditions and the 1955 crop was injured to the extent that it was not harvested in 1956.

Some yearly increases in hay yield due to lime occurred and significant year and lime interactions were obtained. These tend to minimize the importance of significant lime differences which were also obtained on the average for the entire experimental period. Since lime was virtually ineffective and significant treatment-lime interactions did not occur the alfalfa-brome yields presented in Tables 7 and 8 are treatment means over lime levels.

Generally, rock phosphate was as effective in producing increases in first year hay yields as the higher rate of superphosphate. Little benefit was derived from the combination of the two materials beyond that obtained with rock phosphate alone or the higher rate of superphosphate alone. The lower rate of superphosphate was insufficient to produce significant increases in yield of hay.

On second year hay, rock phosphate was not as effective in increasing yields as the higher rate of superphosphate. However, the rock phosphate was more effective than the lower rate of superphosphate which had

TABLE 7. YIELD OF FIRST YEAR ALFALFA-BROME AT THE KALAMAZOO COUNTY LOCATION

Treatment (per acre)	Tons per Acre 1952 1st	1952 2nd	1953 1st	1953 2nd	1956 1st	Ave. 1st	Ave. 2nd
No phosphate fertilizer	2.04	0.73	1.90	0.21	0.96	1.63	0.47
10 lbs. P_2O_5(0-20-0)per year	2.04	0.81	1.92	0.24	0.89	1.61	0.52
20 lbs. P_2O_5(0-20-0)per year	2.05	0.86	2.36	0.21	0.97	1.79	0.53
320 lbs. P_2O_5(rock)1951	2.06	0.94	2.37	0.27	0.91	1.77	0.60
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	1.99	0.83	2.23	0.25	0.94	1.71	0.54
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	2.37	0.93	2.20	0.22	1.13	1.89	0.57
L.S.D.(5% level)	n.s.	n.s.	0.29	0.06	n.s.	0.14	0.08

Analysis of Variance:

Source of Variation	Degrees of freedom 1st	Degrees of freedom 2nd	Mean square 1st	Mean square 2nd	"F" test 1st	"F" test 2nd
Total	143	95				
Replicates	9	6	1.910	0.0617	11.17**	0.45 n.s.
Years(Y)	2	1	21.700	9.13	126.90**	66.16**
Lime(L)	1	1	1.580	0.510	9.24*	3.70 n.s.
L x Y	2	1	1.365	0.02	7.98	0.14 n.s.
Error(a)	9	6	0.171	0.138		
Treatments(T)	5	5	0.270	0.0340	4.52**	2.66*
T x L	5	5	0.046	0.0060	0.77 n.s.	0.47 n.s.
T x Y	10	5	0.142	0.0240	2.38*	1.88 n.s.
T x Y x L	10	5	0.087	0.0100	1.46 n.s.	0.78 n.s.
Error(b)	90	60	0.0597	0.0128		

TABLE 8. YIELD OF SECOND YEAR ALFALFA-BROME AT THE KALAMAZOO COUNTY LOCATION

Treatment (per acre)	1952 1st	1952 2nd	1953 1st	1953 2nd	1954 1st	1955 1st	Ave. 1st	Ave. 2nd
	Tons per Acre							
No phosphate fertilizer	1.71	0.60	1.65	0.31	0.79	1.12	1.32	0.45
10 lbs. P_2O_5(0-20-0)per year	1.81	0.59	1.65	0.32	1.05	1.09	1.39	0.46
20 lbs. P_2O_5(0-20-0)per year	1.97	0.64	1.78	0.33	1.29	1.09	1.52	0.49
320 lbs. P_2O_5(rock)1951	1.68	0.68	1.61	0.32	1.18	1.25	1.42	0.50
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	1.89	0.75	1.72	0.32	1.28	1.10	1.49	0.53
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	1.95	0.64	1.83	0.33	1.15	1.22	1.54	0.48
L.S.D.(5% level)	n.s.	n.s.	n.s.	n.s.	0.32	n.s.	0.14	n.s.

Analysis of variance:

Source of Variation	Degrees of freedom 1st	Degrees of freedom 2nd	Mean square 1st	Mean square 2nd	"F" test 1st	"F" test 2nd
Total	191	95				
Replicates	12	6	0.225	0.983	1.27 n.s.	6.55*
Years(Y)	3	1	6.610	2.570	37.41**	171.33**
Lime(L)	1	1	5.430	0.330	30.73**	22.00**
L x Y	3	1	1.570	0.160	8.89**	10.67**
Error(a)	12	6	0.1767	0.015		
Treatments(T)	5	5	0.236	0.014	2.94*	0.70 n.s.
T x L	5	5	0.120	0.020	1.49 n.s.	1.00 n.s.
T x Y	15	5	0.0867	0.014	1.08 n.s.	0.70 n.s.
T x Y x L	15	5	0.0647	0.008	0.81 n.s.	0.40 n.s.
Error(b)	120	60	0.08025	0.020		

little, if any, effect. As with the first year hay the combination of the two materials gave no additional benefit over that derived from either material used alone.

The relative effectiveness between treatments is not as clear-cut as with the oat crop because of the missing harvests, generally poor growth and only slight phosphate response. However, since the higher rate of superphosphate and the rock phosphate treatment did give measurable yield increases some credence could be assigned to the effectiveness values for these two treatments.

The increases in yield with the first year hay crop were small and yield increases per pound of P_2O_5 applied amounted to 12.2 pounds of hay with the high rate of superphosphate and 4.2 pounds with the rock phosphate. The value for superphosphate included two years of superphosphate addition without harvestable yields (1954, 1955). If these years can be ignored as not representative of treatment the effectiveness value for superphosphate is 20.2 pounds of hay. The value for rock phosphate would not change since the material was added at the beginning of the experiment. Depending on how the comparison is made the relative effectiveness of superphosphate was three or five times that of rock phosphate in increasing first year hay yields.

On second-year hay, the effectiveness value for the high rate of superphosphate is 23.0 pounds of hay per pound of P_2O_5 applied and for rock phosphate, 3.4 pounds. This indicates that the relative effectiveness of superphosphate was nearly seven times that of rock phosphate in increasing second-year alfalfa yields. The effectiveness of superphosphate in these experiments is even of greater significance when the acid reaction of the soil, pH less than 6.0, is considered. Under these conditions rock phosphate has been considered to be more effective than superphosphate.

Genesee County

The Genesee County experiments were locates on the G. Harold Leach farm 2 miles north of Davison in section 34, township 8 north, range 8 east.

This is a major dairy and cash crop area, well within the boundaries of the Detroit milk-shed. Dairying is the most important enterprise for the area and on many of the commercial farms is the sole source of income. Off-farm opportunities are great, however, owing to the influence of metropolitan Detroit.

The length of the growing season in this area is from 150 to 170 days. The last frost in the spring occurs sometime between May 1 and 10 and the first in the fall between October 1 and 10. The elevation ranges from 600 to 800 feet above sea level with the general topography level to rolling (40).

The soils in this general area were derived mainly from loam glacial till. The drainage of the soils varies from well to imperfect with the latter condition generally associated with the smoother locations. The closely associated wet areas, both organic and mineral, often influence the size and shape of fields. Locally, slopes are excessively steep and may have deteriorated because of water erosion (113).

The soils are deep, relatively high in fertility, and durable under cultivation except on the steeper slopes. Under a good system of management the soils can be maintained in a good state of productivity. The soils are suitable for growing such staple crops as corn, wheat, oats, alfalfa, beans and sugar beets (113). The 1947 to 1951 average yields of field crops in the county were as follows: corn, 37 bushels; oats, 41 bushels; wheat, 26 bushels; hay, 1.5 tons per acre (40).

The soils of the experimental area were not very uniform but were characteristic for this area of the state. Approximately four-fifths of the experimental area was divided evenly between the two soil types Blount loam and Metea sandy loam and the remainder of the area was comprised of Morley loam and Pewamo silt loam. The surface was nearly level with a few plots located on gently sloping land. This small area of sloping land was moderately eroded (Class 2) while the bulk of the area was not eroded or slightly eroded (Classes 0, 1) (100).

In 1950 1½ tons per acre of ground limestone was applied to appropriate blocks so that one-half of the area was limed. With an original pH of 5.9 to 6.1 the lime requirement for these soils was 2½ to 3½ tons per acre (86). As a result of under-liming the acid condition was corrected only to pH 6.1 to 6.5.

Of the eight cropping years (1950-1957) at this location, four years, 1953, 1954, 1955 and 1957 were characterized by late summer droughts. In the case of these experiments, however, the effect of dry weather was not as drastic as in Kalamazoo County because of the better water relationships of these soils. In 1952 the climate was warm with sufficient rainfall to produce good yields. The other years had adequate rainfall but were relatively cool.

Corn. The corn yields were very good in 1952, poor in 1951 and 1957 and above average during the other years. The effects of the lime on corn yields were not significant whether considered yearly or as an average.

Since liming was not significant the yields presented in Table 9 are treatment means over lime levels.

Treatment means were significantly different at the 5% level in 1954 and 1956. The higher rate of superphosphate and the combination of the two materials produced significantly higher yields than that obtained without phosphate. These differences carried through into the average for the eight years. The mean yield, produced by the low rate of superphosphate, was higher than that of the rock phosphate though not significantly, six out of the eight years. The average yield obtained with the rock phosphate, however, over the eight years, was lower than that produced without phosphate.

The net increase in yields of corn produced by phosphate fertilization, the total amount of phosphate applied and the effectiveness values over the eight year period are given in Table 10. The rock phosphate treatments had a net deficit in the increased yield value which can be assumed zero response. As a result the relative effectiveness of superphosphate to rock phosphate is infinite.

The soil tests for phosphorus on samples taken prior to corn planting are given in Table 11. As in the Spurway tests in Kalamazoo County the plots treated with rock phosphate all gave "high" soil tests for phosphorus and all other plots gave "low" tests. Since yields from plots with rock phosphate alone averaged less than those from the plots with no phosphate, this test is misleading. The Spurway "reserve" extractant apparently removes phosphorus from the rock phosphate which plants cannot remove.

The Bray adsorbed phosphorus test on the other hand, shows low-medium tests for all treatments and a need for considerable amounts of phosphorus.

TABLE 9. YIELD OF CORN AT THE GENESEE COUNTY LOCATION

Treatment(per acre)	Bushels per Acre 1950	1951	1952	1953	1954	1955	1956	1957	Ave.
No phosphate fertilizer	47.7	24.7	84.5	43.8	47.6	58.9	62.4	41.0	51.3
10 lbs. P_2O_5(0-20-0)per year	42.8	26.3	89.4	42.0	49.9	58.5	67.3	43.4	52.4
20 lbs. P_2O_5(0-20-0)per year	49.9	29.3	94.4	40.7	56.5	62.4	70.6	48.0	56.5
320 lbs. P_2O_5(rock)1950	45.5	22.6	85.8	46.4	47.9	54.1	63.3	41.5	50.9
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	46.0	26.5	91.2	45.7	57.2	59.7	69.0	44.0	54.9
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	46.1	27.9	91.6	48.8	56.1	56.9	68.7	48.0	55.5
L.S.D.(5% level)	n.s.	n.s.	n.s.	n.s.	7.0	n.s.	5.0	n.s.	2.4

Analysis of Variance:

Source of Variation	Degrees of freedom	Mean square	"F" test
Total	383		
Replicates	24	253.15	1.77 n.s.
Years(Y)	7	16,860.51	117.82**
Lime(L)	1	313.02	2.19 n.s.
L x Y	7	188.60	1.32 n.s.
Error(a)	24	143.10	
Treatments(T)	5	350.53	7.35**
T x L	5	118.55	2.48*
T x Y	35	43.98	0.92 n.s.
T x Y x L	35	44.55	0.93 n.s.
Error(b)	240	47.72	

TABLE 10. NET INCREASE IN YIELD OF CORN IN 8 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GENESEE COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Bushels Increase in Yield	Effectiveness Value Bu/lb P_2O_5
10 lbs. P_2O_5(0-20-0)per year	80	9.0	0.11
20 lbs. P_2O_5(0-20-0)per year	160	41.2	0.26
320 lbs. P_2O_5(rock)1950	320	-3.5	-0.01
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	400	28.7	0.07
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	480	33.5	0.07

TABLE 11. AVAILABLE SOIL PHOSPHORUS+ PRIOR TO CORN PLANTING AT THE GENESEE COUNTY LOCATION

	Pounds per Acre											
	1953		1954		1955		1956		1957		Ave.	
Treatment(per acre)	S	P_1	S	P_1	S	P_1	S	P_1	S	P_1	S	P_1
No phosphate fertilizer	14	19	4	15	9	16	18	16	14	15	11	16
10 lbs. P_2O_5(0-20-0)per year	10	18	7	17	10	17	20	17	10	14	12	17
20 lbs. P_2O_5(0-20-0)per year	13	19	9	19	12	18	38	20	12	16	18	18
320 lbs. P_2O_5(rock)1950	65	19	57	17	42	18	58	18	40	14	47	17
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	81	21	59	18	36	18	61	19	46	17	54	19
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	88	21	67	19	51	21	51	19	50	18	55	19
L.S.D.(5% level)	--	n.s.	18	2	8	2	23	n.s.	30	2	8	1

+ S = Spurway reserve test (Extract is 0.13N HCl, 1:4 soil:extract ratio)

P_1= Bray adsorbed phosphorus test (Extract is 0.025N HCl + 0.03N NH_4F, 1:7 soil:extract ratio)

As was true in the case of the Kalamazoo experiment, the Bray test gave the best prediction as to crop response to phosphorus in this test also.

The phosphorus analyses of the plant tissue are presented in Table 12. There were no significant differences, between phosphate treatments or liming on phosphorus content, in either the leaf samples taken at tasseling time or the grain.

Oats. Oat yields were generally above average for the area except in 1955 when yields were poor and in 1957 when the plots were drowned out by spring rains. In 1953, when the corn crop failed at the Kalamazoo location and the oat crop was poor, the Genesee location had the best oat crop of the experiment. The oat yield data and analysis of variance summary are presented in Table 13. Liming did not have a significant effect on oat yields nor were there significant lime interactions so the data in Table 13 are treatment means over lime levels.

In four years, 1952, 1953, 1954, 1955 as in the final analysis, treatment means were significantly different at the 1% level and in one year, 1951 at the 5% level. During the five years of significant treatment effects the plots treated with rock phosphate did not exhibit significant yield increases. Superphosphate consistently produced greater yields than the rock and no phosphate treatments. Only in one year, 1956, did rock phosphate produce a greater yield, though not significant, than the lowest rate of superphosphate. The effects of the combination of the two materials was not greater than that attributable to superphosphate alone.

The net increase in yield of oats produced by phosphate fertilization, the total amount of phosphate applied and the effectiveness values between treatments over the seven year period are presented in Table 14. The lower

TABLE 12. TOTAL PHOSPHORUS IN THE GREEN TISSUE AND HARVESTED GRAIN OF CORN AT THE GENESEE COUNTY LOCATION

	Percent Phosphorus						
	1955	1956		1957		Ave.	
Treatment(per acre)	Leaves	Leaves	Grain	Leaves	Grain	Leaves	Grain
No phosphate fertilizer	0.172	0.211	0.370	0.204	0.309	0.196	0.339
10 lbs. P_2O_5(0-20-0)per year	0.180	0.181	0.407	0.219	0.285	0.193	0.345
20 lbs. P_2O_5(0-20-0)per year	0.172	0.232	0.433	0.234	0.320	0.213	0.377
320 lbs. P_2O_5(rock)1950	0.189	0.227	0.416	0.209	0.327	0.207	0.371
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	0.191	0.241	0.450	0.253	0.328	0.228	0.389
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	0.173	0.205	0.427	0.218	0.330	0.198	0.378
L.S.D.(5% level)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

TABLE 13. YIELD OF OATS AT THE GENESEE COUNTY LOCATION

Treatment (per acre)	Bushels per Acre 1950	1951	1952	1953	1954	1955	1956	Ave.
No phosphate fertilizer	47.2	41.6	42.5	57.7	57.1	32.5	57.4	48.0
10 lbs. P_2O_5(0-20-0)per year	56.5	49.9	46.5	69.7	62.4	36.5	61.9	54.8
20 lbs. P_2O_5(0-20-0)per year	53.4	53.2	48.0	76.7	64.1	41.9	64.6	57.4
320 lbs. P_2O_5(rock)1950	49.9	46.4	37.2	59.3	57.3	33.8	63.0	49.5
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	54.4	49.7	46.5	74.8	67.9	33.9	70.7	56.8
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	53.5	46.5	48.0	73.8	65.9	43.3	66.8	56.8
L.S.D.(5% level)	n.s.	6.1	5.6	10.9	3.8	6.5	n.s.	2.8

Analysis of Variance:

Source of Variation	Degrees of freedom	Mean square	"F" test
Total	335		
Replicates	21	271.07	1.66 n.s.
Years(Y)	6	6,428.78	39.29**
Lime(L)	1	305.91	1.87 n.s.
L x Y	6	80.40	0.49 n.s.
Error(a)	21	163.64	
Treatments(T)	5	939.87	16.37**
T x L	5	14.75	0.26 n.s.
T x Y	30	74.32	1.29 n.s.
T x Y x L	30	70.21	1.22 n.s.
Error(b)	210	57.42	

TABLE 14. NET INCREASE IN YIELD OF OATS IN 7 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GENESEE COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Bushels Increase In Yield	Effectiveness Value Bu/lb P_2O_5	Effectiveness Value Relative
10 lbs. P_2O_5(0-20-0)per year	70	47.4	0.68	22
20 lbs. P_2O_5(0-20-0)per year	140	75.9	0.54	18
320 lbs. P_2O_5(rock)1950	320	10.9	0.03	1
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	390	61.9	0.16	5
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	460	61.8	0.13	4

rate of superphosphate resulted in a net increase in yield over the seven years, of 47.4 bushels per acre with 70 pounds of P_2O_5 applied or an effectiveness value of 0.68 bushels per pound of P_2O_5. The rock phosphate treatment yielded only 10.9 bushels per acre net increase over this period or 0.03 bushels per pound of P_2O_5. Superphosphate, therefore, at the productivity level attained at the lower rate of application, had a relative effectiveness 22 times that of the rock phosphate. At the higher rate of application superphosphate was 18 times as effective as rock phosphate. The combination of the two materials resulted in a relative effectiveness greater than rock phosphate alone but considerably under that of superphosphate alone. The treatment of the low rate of superphosphate plus rock phosphate produced a greater net yield increase than superphosphate alone. The net yield, in this case, was slightly greater than the additive effect of each material.

Representative plant samples were taken from the plots in 1954, 1955 and 1956 at heading time and were analyzed for total phosphorus. These data are presented in Table 15. Lime did not affect the phosphorus content so data given are treatment means over lime levels. All phosphate treatments significantly increased phosphorus in the young plants. The rock phosphate treatments increased phosphorus content in the young plants but did not increase final yield.

Hay. Alfalfa-brome yields were well above average for the entire period. Only in 1954 did dry weather reduce yields of the second cuttings to where they were unharvestable. The yield data for first and second year hay are presented in Tables 16 and 19, respectively.

Lime significantly increased yields of both first and second cuttings

TABLE 15. TOTAL PHOSPHORUS IN THE OATS SAMPLED AT HEADING TIME AT THE GENESEE COUNTY LOCATION

Treatment (per acre)	Percent Phosphorus 1954	1955	1956	Ave.
No phosphate fertilizer	0.232	0.193	0.230	0.218
10 lbs. P_2O_5 (0-20-0) per year	0.259	0.196	0.276	0.244
20 lbs. P_2O_5 (0-20-0) per year	0.229	0.220	0.276	0.241
320 lbs. P_2O_5 (rock) 1950	0.230	0.229	0.270	0.243
320 lbs. P_2O_5 (rock) 1950 plus 10 lbs. P_2O_5 (0-20-0) per year	0.253	0.274	0.278	0.257
320 lbs. P_2O_5 (rock) 1950 plus 20 lbs. P_2O_5 (0-20-0) per year	0.246	0.237	0.284	0.256
L.S.D. (5% level)	n.s.	n.s.	n.s.	0.022

TABLE 16. YIELD OF FIRST YEAR ALFALFA-BROME AT THE GENESEE COUNTY LOCATION

Treatment(per acre)	1952 1st	1952 2nd	1953 1st	1953 2nd	1954 1st	1955 1st	1955 2nd	1956 1st	1956 2nd	1957 1st	1957 2nd	Ave. 1st	Ave. 2nd
	Tons per Acre												
No phosphate fertilizer	0.93	0.53	1.07	1.05	1.31	0.92	1.29	1.22	0.88	1.48	0.73	1.15	0.89
10 lbs. P_2O_5(0-20-0)per year	1.22	0.74	1.55	1.40	1.45	0.77	1.46	1.45	0.91	1.66	0.84	1.35	1.06
20 lbs. P_2O_5(0-20-0)per year	1.27	0.87	1.48	1.32	1.59	0.97	1.52	1.57	0.97	1.69	0.75	1.42	1.08
320 lbs. P_2O_5(rock)1950	0.97	0.86	1.07	1.19	1.39	0.97	1.40	1.52	0.99	1.60	0.80	1.25	1.04
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	1.31	0.97	1.49	1.48	1.76	0.95	1.56	1.58	1.00	1.92	0.86	1.50	1.17
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	1.28	0.98	1.51	1.44	1.88	1.04	1.63	1.64	1.06	2.06	0.91	1.56	1.20
L.S.D.(5% level)	0.29	0.22	0.27	0.18	0.21	n.s.	n.s.	0.19	n.s.	n.s.	n.s.	0.11	0.11

Analysis of Variance:

Source of Variation	Degrees of freedom (1)	Degrees of freedom (2)	Mean square (1)	Mean square (2)	"F" test (1)	"F" test (2)
Total	287	239				
Replicates	18	15	0.455	0.467	3.07*	2.57*
Years(Y)	5	4	3.99	4.367	26.96**	23.83**
Lime(L)	1	1	0.80	2.620	5.41*	14.40**
Y x L	5	4	0.046	0.137	0.31 n.s.	0.75 n.s.
Error(a)	18	15	0.148	0.182		
Treatments(T)	5	5	1.17	0.472	17.13**	7.54**
T x L	5	5	0.036	0.084	0.53 n.s.	1.34 n.s.
T x Y	25	20	0.099	0.041	1.45 n.s.	0.65 n.s.
T x Y x L	25	20	0.090	0.0805	1.32 n.s.	1.29 n.s.
Errors(b)	180	150	0.0683	0.0626		

of the first year hay by 0.11 and 0.20 tons per acre, respectively. However, lime interactions were not significant so that the data presented in Table 16 are treatment means over lime levels. Treatment means were significantly different at the 1% level during five of the eleven harvest periods and at the 5% level for the first cutting in 1952.

Generally, the rock phosphate treatment was not as effective in increasing yields as the lowest rate of superphosphate, although rock phosphate did significantly increase yields. The combination of the two materials, in contrast to previously mentioned trials, resulted in significantly greater yields than that attributable to either material alone. In fact, the effect of the two materials was roughly additive.

In considering the net increase over the entire period, and the effectiveness of the different treatments as presented in Table 17, it is apparent that the combination of the two materials is not the most effective treatment. The combination at either rate of superphosphate while twice as effective as rock phosphate alone were only 40% as effective as the higher rate of superphosphate alone and only 25% that of the lower rate of superphosphate.

Superphosphate alone, at the lowest rate of application, produced a higher net yield increase than the rock phosphate. At the yield level attained by this rate of application the relative effectiveness of superphosphate on first year hay was eight times that of the rock phosphate. At the higher rate of application superphosphate was five times as effective as the rock phosphate.

Plant analyses for total phosphorus were made on the second cuttings of the first year hay in 1953, 1955, 1956 and 1957 and on the first cutting in 1957. These data are presented in Table 18 as treatment means

TABLE 17. NET INCREASE IN YIELD OF FIRST YEAR HAY IN 6 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GENESEE COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Tons Increase in Yield	Effectiveness Value Pounds/lb P_2O_5	Relative
10 lbs. P_2O_5(0-20-0)per year	60	2.04	68.0	8
20 lbs. P_2O_5(0-20-0)per year	120	2.59	44.0	5
320 lbs. P_2O_5(rock)1950	320	1.35	8.4	1
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	380	3.47	18.2	2
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	440	4.02	18.2	2

TABLE 18. TOTAL PHOSPHORUS IN THE FIRST YEAR HAY CROP+AT THE GENESEE COUNTY LOCATION

Treatment(per acre)	Percent Phosphorus 1953	1955	1956	(1) 1957	(2)	Ave.
No phosphate fertilizer	0.166	0.196	0.223	0.114	0.211	0.199
10 lbs. P_2O_5(0-20-0)per year	0.172	0.175	0.256	0.153	0.208	0.203
20 lbs. P_2O_5(0-20-0)per year	0.191	0.215	0.252	0.135	0.247	0.226
320 lbs. P_2O_5(rock)1950	0.161	0.200	0.251	0.161	0.228	0.212
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	0.188	0.208	0.230	0.131	0.214	0.210
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	0.186	0.224	0.238	0.143	0.219	0.217
L.S.D.(5% level)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

+ The analysis made on second cuttings only in 1953, 1955 and 1956. Both cuttings were analyzed in 1957. The average is of second cuttings only.

over lime levels.

Liming did not have a significant effect on phosphorus content nor were there significant lime interactions. Phosphate treatments, likewise, did not produce statistically significant differences in phosphorus content although, generally, the hay fertilized with phosphate had higher phosphorus percentages than that without phosphate.

The second year hay yields were not significantly affected by liming although there was a highly significant lime-treatment interaction. This interaction was caused by a substantial increase in yield upon liming on the plots without phosphate and a slight decrease in yield on all of the plots with phosphate regardless of difference in phosphate source. The yields presented in Table 19 are treatment means over lime levels.

The treatment means were significantly different at the 1% level in nine of the eleven harvest periods and at the 5% level for the second cutting in 1955. Considering the average over the entire period the rock phosphate treatment was roughly equivalent to the higher rate of superphosphate in yields produced. The lower rate of superphosphate while producing a significant increase in yield was significantly lower in yield than that of the rock phosphate treatments. Generally, the combination of the two materials produced higher yields than either material alone, but not additively. However, these yields were not significantly greater than that obtained with rock phosphate alone.

The net increase in yield and effectiveness values for the phosphate treatments on second year hay are presented in Table 20. The effectiveness of the rock phosphate while less than that of superphosphate was considerably more than that shown in previous trials. Superphosphate, at either rate of application was only 2.5 times as effective as the rock

TABLE 19. YIELD OF SECOND YEAR ALFALFA-BROME AT THE GENESEE COUNTY LOCATION

Treatment (per acre)	1952 1st	1952 2nd	1953 1st	1953 2nd	1954 1st	1955 1st	1955 2nd	1956 1st	1956 2nd	1957 1st	1957 2nd	Ave. 1st	Ave. 2nd
	Tons per Acre												
No phosphate fertilizer	2.46	1.25	1.41	1.50	1.46	1.49	1.07	1.84	1.15	1.58	1.02	1.70	1.19
10 lbs. P_2O_5(0-20-0)per year	2.07	0.93	1.86	2.40	1.64	1.96	1.32	1.84	0.94	2.03	1.17	1.90	1.35
20 lbs. P_2O_5(0-20-0)per year	2.58	1.18	2.14	2.56	1.73	2.40	1.36	2.02	1.10	1.94	1.28	2.13	1.49
320 lbs. P_2O_5(rock)1950	2.81	1.26	2.06	2.18	1.57	2.25	1.56	1.97	1.48	1.97	1.21	2.10	1.53
320 lbs. P_2O_5(rock)1950 10 lbs. P_2O_5(0-20-0)per year	2.83	1.50	2.30	2.81	1.68	2.45	1.33	2.10	1.05	2.09	1.16	2.24	1.56
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	3.03	1.56	2.33	2.97	1.71	2.37	1.19	2.07	1.40	1.87	1.29	2.23	1.68
L.S.D.(5% level)	0.37	0.27	0.29	0.61	0.08	0.33	0.29	n.s.	0.30	0.21	0.14	0.15	0.16

Analysis of Variance:

Source of Variation	Degrees of freedom (1)	Degrees of freedom (2)	Mean square (1)	Mean square (2)	"F" test (1)	"F" test (2)
Total	287	239				
Replicates	18	15	0.465	0.859	2.61*	0.33 n.s.
Years (Y)	5	4	5.322	13.20	29.90**	5.02**
Lime(L)	1	1	0.020	2.07	0.11 n.s.	0.79 n.s.
Y x L	5	4	0.220	0.435	1.24 n.s.	0.16 n.s.
Error(a)	18	15	0.178	2.63		
Treatments(T)	5	5	2.122	1.200	30.98**	9.52**
T x L	5	5	0.218	0.048	3.18**	0.38 n.s.
T x Y	25	20	0.258	0.518	3.77**	4.11**
T x Y x L	25	20	0.133	0.1025	1.94**	0.81 n.s.
Error (b)	180	150	0.0685	0.1261		

TABLE 20. NET INCREASE IN YIELD OF SECOND YEAR HAY IN 6 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GENESEE COUNTY LOCATION

Treatment (per acre)	Pounds P_2O_5 Applied	Tons Increase in Yield	Effectiveness Values Pounds per lb P_2O_5	Relative
10 lbs. P_2O_5 (0-20-0) per year	60	1.93	64	2.5
20 lbs. P_2O_5 (0-20-0) per year	120	4.06	68	2.5
320 lbs. P_2O_5 (rock) 1950	320	4.09	26	1
320 lbs. P_2O_5 (rock) 1950 plus 10 lbs. P_2O_5 (0-20-0) per year	380	5.07	26	1
320 lbs. P_2O_5 (rock) 1950 plus 20 lbs. P_2O_5 (0-20-0) per year	440	5.56	26	1

phosphate in increasing yield.

Plant analyses for phosphorus were made on the second cuttings of the second year hay in 1953, 1955, 1956 and 1957. In 1957 the first cutting was also analyzed. These data are presented in Table 21 as treatment means over lime levels.

Liming did not have a significant effect of phosphorus in the plant nor were there significant lime interactions. The average for the second cuttings shows all phosphate treatments producing higher phosphorus percentages in the plant than those without phosphate. Only the higher rate of superphosphate and the combination treatments were significantly greater.

Iosco County

The experiments in Iosco County were located on the James Mielock farm, 17 miles west of Tawas City in section 20 of township 22, north, range 5 east.

This area of the state does not have the good local markets that are found in the more southern counties. The farming is largely comprised of livestock of a diversified nature for there are many beef as well as daily cattle. The sales of dairy products and those of livestock and livestock products, other than dairy and poultry, are about equal (40). There are also large acreages of state owned land dedicated to forestry, parks and recreation.

The growing season in this area ranges from 110 to 130 days. The last frost in the spring occurs between May 20 and 31 and the first frost in the fall between Sept. 20 and 30. The elevation is 600 to 800 feet above sea level with the topography ranging from level to rolling.

The soils are mainly formed from glacial tills of clay loam to silty

TABLE 21. TOTAL PHOSPHORUS IN THE SECOND YEAR HAY CROP+ AT THE GENESEE COUNTY LOCATION

Treatment(per acre)	Percent Phosphorus 1953	1955	1956	(1) 1957	(2)	Ave.
No phosphate fertilizer	0.134	0.158	0.201	0.149	0.204	0.174
10 lbs. P_2O_5(0-20-0)per year	0.150	0.193	0.197	0.161	0.180	0.180
20 lbs. P_2O_5(0-20-0)per year	0.172	0.183	0.205	0.161	0.209	0.192
320 lbs. P_2O_5(rock)1950	0.154	0.196	0.183	0.116	0.208	0.185
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	0.157	0.202	0.213	0.181	0.202	0.193
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	0.161	0.206	0.265	0.202	0.201	0.209
L.S.D.(5% level)	0.018	n.s.	0.032	n.s.	n.s.	0.017

+ The analyses made on second cuttings only in 1953, 1955 and 1956. Both cuttings were analyzed in 1957. The average is of second cuttings only.

clay loam in texture. Drainage varies from well to imperfect with the latter condition generally associated with the more level locations. The soils are deep, relatively high in fertility and durable under cultivation, except on the steeper slopes (113). The 1947-1951 average per acre yields of field crops in Iosco County were as follows: corn, 32 bushels; oats, 34 bushels; hay 1.3 tons (40).

The soils of the experimental area were variable, comprising 9 soil types, which is characteristic of the soil distribution for this area. These soils, however, were mainly of one soil management group, the imperfectly drained loamy soils. The predominant soil types of the experimental area were Kawkawlin loam and Kawkawlin sandy loam. The other soil types were Ubly sandy loam, Isabella sandy loam, Nester loam, Nester sandy loam, Twining sandy loam, Belding sandy loam and Sims loam. The surface was gently undulating to nearly level with very slight surface erosion (Classes 0, 1) (100).

The climate at this location was less variable than that at the more southern locations. Relatively, however, 1952, 1953 and 1955 were warm years. Only in 1955 were there periods of moisture deficiency.

Corn. The corn plots were harvested only in 1952. Yield differences between treatments were not significant and soil and plant analyses were not conducted. Subsequent soil tests showed similar results to the Genesee County location.

Wheat. There were only three years with harvestable wheat yields, 1952, 1953 and 1954. In 1952, at the beginning of the experiment, three of the four fields were planted to wheat, the fourth in corn. In order to gain accuracy in the estimate of the effect of the treatments on wheat by having a larger number of trials the three fields of 1952 are included in the data presented in Table 22. These fields and the results of 1953 and 1954 are included in the analysis of variance in the term, "experiments."

Two of the fields in 1952, the Northeast and Northwest quadrangles, and the 1954 trial showed significant treatment differences. These experiments were subjected to a substantial error variance, however, as evidenced by the large L.S.D. values. This is probably due to the rather extreme soil variability. As a result of the large error variance, tests for significance within each experiment were difficult to interpret. By combining all the data this error term is reduced and greater reliance can be placed on the average as indicative of treatment effects.

The analysis of variance for treatment means over the entire experiment shows significant differences at the 1% level. The rock phosphate treatments produced a higher average yield but not significantly, than that obtained without phosphate. Superphosphate, regardless of rate, produced significantly higher yields than either the rock phosphate or the no phosphate treatments. Differences in yield produced between rates of superphosphate were not significant. The combination of rock phosphate and superphosphate did not result in yields greater than that attributable to superphosphate alone.

In calculating the net increase in yield of wheat and the total amount of P_2O_5 applied as presented in Table 23 it had to be assumed that the effect of the rock phosphate applied for the three fields in 1952 would be similar to that on one field over three years. This averaging of three trials planted immediately after rock phosphate application with

TABLE 22. YIELD OF WHEAT AT THE IOSCO COUNTY LOCATION

Treatment (per acre)	1952 SE	1952 NE	1952 NW	1953	1954	Ave.
	Bushels per Acre					
No phosphate fertilizer	31.6	34.6	24.9	17.0	16.9	25.0
10 lbs. P_2O_5(0-20-0)per year	40.9	35.9	34.3	25.3	22.1	31.7
20 lbs. P_2O_5(0-20-0)per year	37.7	36.2	37.6	24.5	27.8	32.7
320 lbs. P_2O_5(rock)1951	35.1	25.2	28.2	22.2	20.4	26.2
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	39.6	38.2	31.5	23.2	24.3	31.3
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	40.9	36.8	31.5	26.8	24.3	32.1
L.S.D.(5% level)	n.s.	7.6	7.1	n.s.	7.8	3.0

Analysis of Variance

Source of Variation	Degrees of freedom	Mean square	"F" test
Total	119		
Replicates	15	76.81	3.33**
Experiments(E)	4	1086.00	47.05**
Treatments(T)	5	223.55	9.69**
T x E	20	25.53	1.11 n.s.
Error		23.08	

TABLE 23. THE NET INCREASE IN YIELD OF WHEAT IN 5 EXPERIMENTS PRODUCED BY PHOSPHATE FERTILIZATION AT THE IOSCO COUNTY LOCATION

Treatment (per acre)	Pounds P_2O_5 Applied	Bushels Increase in Yield	Effectiveness Values Bu/lb P_2O_5	Effectiveness Values Relative
10 lbs. P_2O_5 (0-20-0) per year	50	33.5	0.67	33
20 lbs. P_2O_5 (0-20-0) per year	100	38.8	0.39	20
320 lbs. P_2O_5 (rock) 1951	320	6.1	0.02	1
320 lbs. P_2O_5 (rock) 1951 plus 10 lbs. P_2O_5 (0-20-0) per year	370	31.8	0.08	4
320 lbs. P_2O_5 (rock) 1951 plus 20 lbs. P_2O_5 (0-20-0) per year	420	35.3	0.08	4

those of later years minimized the long-term effect of the rock phosphate, but since the data were obtained over a three year period little long term evaluation is possible.

The effectiveness of superphosphate at the low rate of application was 33 times that of the rock phosphate under the conditions previously described. At the higher rate of application superphosphate was 20 times as effective. The combination treatments were more effective than rock phosphate alone but considerably less than superphosphate alone. Since the magnitude of the increases in yield of the combination treatments was no greater than that of superphosphate alone the effectiveness of the combination treatments would be ascribed only to the superphosphate.

Hay. There were only two years of harvestable hay yields, 1954 and 1955 and first cuttings only were sampled for yield. These data are presented in Table 24.

The first year alfalfa in 1954 showed significant yield increases for all phosphate treatments without significant differences between forms or rates. The differences in yield in 1955 were not significant, however, the average of both years, 1954 and 1955 shows similar significant effects to those obtained in 1954. In addition, the high rate of superphosphate produced a significantly higher yield than the low. Second year hay yields were not statistically different, although all phosphate treatments produced considerably higher yields than the treatment without phosphate.

The net increase in yield for first year alfalfa hay given in Table 25 shows superphosphate at the low rate of application to be 12 times as effective as the rock phosphate and 11 times as effective at the high

TABLE 24. YIELD OF FIRST CUTTING HAY AT THE IOSCO COUNTY LOCATION

	Tons per Acre					
	First year hay			Second year hay		
Treatment(per acre)	1954	1955	Ave.	1954	1955	Ave.
No phosphate fertilizer	1.25	0.96	1.10	1.36	0.85	1.11
10 lbs. P_2O_5(0-20-0)per year	1.88	1.04	1.46	1.47	1.23	1.35
20 lbs. P_2O_5(0-20-0)per year	2.00	1.53	1.76	1.77	1.34	1.56
320 lbs. P_2O_5(rock)1951	2.16	1.00	1.58	1.58	1.51	1.54
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	1.92	1.21	1.56	2.01	1.21	1.61
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	2.09	1.06	1.57	1.62	1.24	1.43
L.S.D.(5% level)	0.35	n.s.	0.25	n.s.	n.s.	n.s.

TABLE 25. THE NET INCREASE IN YIELD OF FIRST YEAR HAY IN 2 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE IOSCO COUNTY LOCATION

Treatment (per acre)	Pounds P_2O_5 Applied	Tons Increase in Yield	Effectiveness Values: Pounds/lb P_2O_5	Effectiveness Values: Relative
10 lbs. P_2O_5 (0-20-0) per year	20	0.71	71	12
20 lbs. P_2O_5 (0-20-0) per year	40	1.32	66	11
320 lbs. P_2O_5 (rock) 1951	320	0.95	6	1
320 lbs. P_2O_5 (rock) 1951 plus 10 lbs. P_2O_5 (0-20-0) per year	340	0.92	6	1
320 lbs. P_2O_5 (rock) 1951 plus 20 lbs. P_2O_5 (0-20-0) per year	360	0.94	6	1

rate of application. The combination of the two materials was of no greater effectiveness than that of rock phosphate alone.

The effect of rock phosphate was greater on second year alfalfa than on the first year alfalfa as shown in Table 26. However, superphosphate was still 8 times more effective than the rock phosphate. The combined materials were a little more effective than rock phosphate alone.

Grand Traverse County

The Grand Traverse County experiments were located on the William Vandrasek farm 10 miles north of Mesick in section 36 of township 25 north, range 12 west.

This general area of the state is largely in dairying and potato farming along with a high proportion of part-time farming. The major enterprise, however, is dairying and about 30 percent of the milk produced is sold as whole milk. The major factors accounting for the selection of crop and livestock enterprises in this area are the sandy loams and the deep dry sandy soils, the relatively short growing season, and the great distance from major markets.

The growing season for this area ranges from 110 to 130 days. The last frost in the spring occurs around May 10 and the first fall frost occurs between September 10 and 20. The elevation in the vicinity of the experimental area was 1000 to 1200 feet above sea level with the topography level to rolling (40).

The soils in this area are dominantly sands, loamy sands and sandy loams with a considerable range in moisture retention, from the soils which are excessively dry to those which are moderately retentive. The soils are generally slightly to strongly acid but the sandy loam parent

TABLE 26. THE NET INCREASE IN YIELD OF SECOND YEAR HAY IN 2 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE IOSCO COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Tons Increase in Yield	Effectiveness Values Pounds/lb P_2O_5	Relative
10 lbs. P_2O_5(0-20-0)per year	20	0.49	48	8
20 lbs. P_2O_5(0-20-0)per year	40	0.90	46	8
320 lbs. P_2O_5(rock)1951	320	0.88	6	1
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	340	1.01	6	1
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	360	0.95	6	1

materials are limy.

The soils are not highly productive and require very careful soil management to obtain satisfactory crop yields. The soils, in general, are low in organic matter, easily tilled, warm up rapidly in the spring, and very responsive to fertilizer and manure. A considerable amount of the sandier land which had previously been cleared has been abandoned. The sandy loam soils are excellent for potato production and produce fair yields of alfalfa, mixed hay and oats (113). The 1947-1951 average for acre yields of field crops in Grand Traverse County were as follows: corn, 29 bushels; wheat 18 bushels; oats, 26 bushels, hay 1.2 tons (40).

The soils of the experimental area were very uniform. Three-fourths of the area was comprised of the soil type Karlin sandy loam with the remainder being McBride sandy loam. The surface was level to gently undulating with very little surface soil lost through erosion (Class 0) (100).

In 1950, 1½ tons per acre of ground limestone was applied to appropriate blocks so that one-half of the area was limed. With an original pH of 5.7 to 5.9 the lime requirement for these soils would be nearer 2½ tons per acre (86). As a result of under-liming the soil acidity was only partially corrected to pH 6.1 to 6.2.

The climate, like that in Iosco County was less variable than that of the more southern counties. Of the seven cropping years, (1951-1957) only 1955 had periods of moisture deficiency which primarily affected hay yields. The rest of the years had sufficient rainfall although of occasional inadequate distribution. In 1956 late summer rains resulted in the loss of the mature oat crop by lodging and mildew. Relatively, 1952, 1953, 1955 and 1957 were warm years.

Corn. The corn yields were rather poor in comparison to those obtained in the better adapted corn growing areas in the southern counties of the state. However, in relation to those obtained in the vicinity of the experimental plots the yields were, generally, well above average.

Liming had a slight benefit on corn yields increasing yields by 3.4 bushels per acre or 8.7 percent. There were no significant lime interactions, however, so that the yield data presented in Table 27 are treatment means over lime levels.

Treatments were significantly different at the 1% level in 1952 and 1957 and at the 5% level in 1954 and 1956. In 1952 the rock phosphate treatment produced a significantly lower yield than the treatment without phosphate but in the other years was not significantly different. The combination of rock phosphate plus superphosphate at the higher rate of application produced significantly higher yields than the treatment without phosphate in 1952, 1956 and 1957. Yields obtained with superphosphate at the low rate in 1956 and at the high rate in 1957 were significantly greater than that produced without phosphate. The average for the seven years, however, does not show a significant difference between rates of superphosphate or between superphosphate alone and the combination treatments. The average yield produced by rock phosphate was less than the treatment without phosphate although not significantly.

The net increase in yields of corn produced by phosphate fertilization and the effectiveness values are given in Table 28. The rock phosphate had a net deficit with respect to increased yield value which can be assumed to be zero response. As a result, the relative effectiveness of

TABLE 27. YIELD OF CORN AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment (per acre)	Bushels per Acre 1951	1952	1953	1954	1955	1956	1957	Ave.
No phosphate fertilizer	34.3	61.0	38.6	39.7	45.8	22.0	24.4	38.0
10 lbs. P_2O_5(0-20-0)per year	38.1	63.0	37.1	39.7	51.0	34.2	29.6	41.8
20 lbs. P_2O_5(0-20-0)per year	38.7	64.4	36.6	41.1	52.7	30.5	33.1	42.4
320 lbs. P_2O_5(rock)1951	36.2	54.0	38.1	37.5	47.9	25.7	20.6	37.1
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	38.2	66.2	37.6	46.4	49.5	35.6	26.6	42.9
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	37.5	72.3	38.6	42.8	47.0	34.1	36.1	44.0
L.S.D.(5% level)	n.s.	5.3	n.s.	5.6	n.s.	8.7	6.2	2.8

Analysis of Variance:

Source of Variation	Degrees of freedom	Mean square	"F" test
Total	335		
Replicates	21	190.92	1.52 n.s.
Years(Y)	6	6,948.47	55.22**
Lime(L)	1	956.13	7.60*
L x Y	6	234.95	1.87 n.s.
Error(a)	21	125.83	
Treatments(T)	5	444.86	7.62**
T x L	5	110.98	1.90 n.s.
T x Y	30	83.57	1.43 n.s.
T x Y x L	30	63.82	1.09 n.s.
Error(b)	210	58.41	

TABLE 28. THE NET INCREASE IN YIELD OF CORN IN 7 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Bushels Increase in Yield	Effectiveness Value Bu/lb P_2O_5
10 lbs. P_2O_5(0-20-0)per year	70	26.9	0.38
20 lbs. P_2O_5(0-20-0)per year	140	31.3	0.22
320 lbs. P_2O_5(rock)1951	320	-5.8	-0.02
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	390	34.6	0.09
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	460	42.6	0.09

superphosphate to rock phosphate is infinite.

The soil tests of samples taken prior to corn planting are given in Table 29. Generally, similar results were obtained as those for the Kalamazoo and Genesee County locations. The Spurway "reserve" tests showed a "low" phosphorus content in the plots treated with superphosphate as well as in those without phosphate. "High" tests were recorded in the plots treated with rock phosphate. Since the plots with rock phosphate alone actually averaged less yield than those without phosphate these tests are misleading. The plots with rock phosphate plus superphosphate also had "high" phosphorus tests by the Spurway method yet these plots showed an apparent significant increase in yield to the superphosphate. Obviously the Spurway strong acid extractant was removing phosphorus from the rock phosphate which was unavailable to plants. This effect is illustrated in Plates I, II, III and IV. The same soil samples tested by the Bray "adsorbed phosphorus" (P_1) shows less difference between treatments than the Spurway method. All treatments however, averaged "high" in phosphorus tests ($>$ 35 lbs. phosphorus per acre). The response of the corn to the applied phosphate is in accord with the soil tests since there was a significant increase in yield with the low rate of superphosphate but a non-significant increase beyond this with the higher rate of superphosphate.

In the Genesee County experiments with generally low-medium Bray tests for phosphorus the corn showed significant yield differences between rates of superphosphate. In the Kalamazoo County experiments, on the other hand with very high Bray tests for phosphorus, averaging around 25 pounds per acre greater than in the Grand Traverse County experiments,

CORN AT THE GRAND TRAVERSE COUNTY LOCATION

Plate I. Limed, no phosphate. Plant 5 inches tall. Spurway reserve P 27 lb/ac. Final yield 31 bu/ac.

Plate II. Limed, rock phosphate. Plant 5 in.tall. Spurway reserve P 58 lb/ac. Final yield 26 bu/ac.

Plate III. Rock phosphate, no lime. Plant 5 inches tall. Note characteristic phosphorus deficiency. Spurway reserve P 102 lb/ac. Final yield 22 bu/ac.

Plate IV. Limed, 10 lb P_2O_5 superphosphate. Plant 10 inches tall. Spurway reserve P 44 lb/ac. Final yield 41 bu/ac.

TABLE 29. AVAILABLE SOIL PHOSPHORUS+ PRIOR TO CORN PLANTING. GRAND TRAVERSE COUNTY

	Pounds per Acre									
	1954		1955		1956		1957		Ave.	
Treatment (per acre)	S	P_1	S	P_1	S	P_1	S	P_1	S	P_1
No phosphate fertilizer	12	30	17	36	28	45	16	40	18	38
10 lbs. P_2O_5 (0-20-0) per year	12	30	18	42	40	52	17	41	22	42
20 lbs. P_2O_5 (0-20-0) per year	14	31	25	44	38	60	21	48	25	46
320 lbs. P_2O_5 (rock) 1951	72	34	58	43	74	51	76	46	70	44
320 lbs. P_2O_5 (rock) 1951 plus 10 lbs. P_2O_5 (0-20-0) per year	66	36	58	44	67	59	72	54	66	48
320 lbs. P_2O_5 (rock) 1951 plus 20 lbs. P_2O_5 (0-20-0) per year	82	37	63	40	78	72	82	61	76	53
L.S.D. (5% level)	20	4	12	n.s.	26	10	17	7	9	4

+ S = Spurway reserve test (Extract is 0.13N HCl, 1:4 soil:extract ratio)
P_1 = Bray adsorbed phosphorus test (Extract is 0.025N HCl + 0.03N NH_4F, 1:7 soil:extract ratio)

the corn exhibited no phosphate response. The Bray "adsorbed phosphorus" (P_1) test, therefore in all cases, gave a better estimate of the response of corn to phosphate than did the Spurway "reserve" test.

The phosphorus analyses of the plant tissue are presented in Table 30. The treatment means were not significantly different nor was the effect of liming significant on phosphorus content in either the leaf samples or in the grain.

<u>Oats</u>. Oat yields were generally average for this area of the state with the exception of 1957 when yields were well above average.

Liming did not have a significant effect on oat yields nor were there significant lime interactions. The oat yield data presented in Table 31, therefore, are treatment means over lime levels.

In 1952, 1953 and 1955 treatment means were significantly different at the 5 percent level with rock phosphate producing a significant yield increase only in 1955. In 1954 as in the average over the six years, treatment means were significantly different at the 1 percent level. The results of 1954 further correspond to those of the six year average in that the superphosphate treatments produced significantly greater yields than either the rock phosphate or the no phosphate. The plots with rock phosphate averaged higher yields than those without phosphate but were not statistically significant. The combination of the two materials did not produce greater yields than that attributable to superphosphate alone.

The net increase in yield of oats produced by phosphate fertilization, the total amount of phosphate applied and the effectiveness values between treatments over the six year period are presented in Table 32. The low rate of superphosphate applied at a total of 60 pounds of P_2O_5, over this

TABLE 30. TOTAL PHOSPHORUS IN THE GREEN TISSUE AND HARVESTED GRAIN OF CORN AT THE GRAND TRAVERSE COUNTY LOCATION

	Percent Phosphorus						
	1955	1956		1957		Ave.	
Treatment(per acre)	Leaves	Leaves	Grain	Leaves	Grain	Leaves	Grain
No phosphate fertilizer	0.217	0.231	0.473	0.238	0.392	0.228	0.433
10 lbs. P_2O_5(0-20-0)per year	0.223	0.241	0.479	0.258	0.412	0.240	0.446
20 lbs. P_2O_5(0-20-0)per year	0.233	0.289	0.502	0.315	0.373	0.279	0.437
320 lbs. P_2O_5(rock)1951	0.236	0.239	0.496	0.276	0.388	0.250	0.442
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	0.229	0.249	0.483	0.239	0.406	0.239	0.445
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	0.255	0.248	0.488	0.299	0.392	0.267	0.440
L.S.D.(5% level)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

TABLE 31. YIELD OF OATS AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment (per acre)	Bushels per Acre 1951	1952	1953	1954	1955	1957	Ave.
No phosphate fertilizer	26.3	20.5	28.8	23.1	46.4	55.3	33.4
10 lbs. P_2O_5(0-20-0)per year	27.0	22.3	33.5	33.3	47.6	61.8	37.6
20 lbs. P_2O_5(0-20-0)per year	30.0	24.2	31.1	35.4	51.4	58.9	38.5
320 lbs. P_2O_5(rock)1951	28.2	16.7	30.0	24.8	52.0	58.1	35.0
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	31.5	24.0	32.4	33.2	51.6	61.9	39.1
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	29.8	24.7	30.0	34.2	51.6	62.6	38.8
L.S.D.(5% level)	n.s.	4.7	3.1	2.6	4.2	n.s.	1.9

Analysis of Variance:

Source of Variation	Degrees of freedom	Mean square	"F" test
Total	287		
Replicates	18	45.90	1.06 n.s.
Years(Y)	5	10,162.29	234.37**
Lime(L)	1	179.08	4.13 n.s.
L x Y	5	54.19	1.25 n.s.
Error(a)	18	43.36	
Treatments(T)	5	260.31	11.49**
T x L	5	5.81	0.26 n.s.
T x Y	25	40.85	1.80*
T x Y x L	25	21.49	0.95 n.s.
Error(b)	180	22.66	

TABLE 32. NET INCREASE IN YIELD OF OATS IN 6 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Bushels Increase in Yield	Effectiveness Values Bushels/lb P_2O_5	Relative
10 lbs. P_2O_5(0-20-0)per year	60	15.1	0.25	8
20 lbs. P_2O_5(0-20-0)per year	120	30.6	0.26	9
320 lbs. P_2O_5(rock)1951	320	9.4	0.03	1
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	380	34.2	0.09	3
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	440	32.5	0.07	2

period, increased oat yields by 15.1 bushels per acre or 0.25 bushels per pounds of P_2O_5. The 320 pounds of P_2O_5 as rock phosphate increased yields by 9.4 bushels per acre or 0.03 bushels per pound of P_2O_5. Superphosphate at the low rate of application, therefore, was 8 times as effective in increasing yields as the rock phosphate. At the high rate of superphosphate, with a total application of 120 pounds of P_2O_5 per acre, the net increase in yield of oats was 30.6 bushels per acre, or 0.26 bushels per pound of P_2O_5 applied. Relative to the rock phosphate the high rate of superphosphate was 9 times as effective in increasing oat yields.

The treatments combining the two materials had greater effect than rock phosphate alone but considerably less than superphosphate alone. The treatment of the low rate of superphosphate plus the rock phosphate produced a net yield increase twice that of superphosphate alone. This result is of greater magnitude than a simple additive effect of both materials. It might be concluded that there was a stimulative effect in the use of the two materials together. However, this effect has not been noted in the other trials nor is it known to have been reported in the literature. In all likelihood this result is entirely within the range of experimental error.

Representative samples of the 1955, 1956 and 1957 oat crops were cut from the plots at time of heading and total phosphorus determined. These data are presented in Table 33 as treatment means over lime levels. Liming did not have a significant effect on phosphorus content nor were there significant lime interactions. Treatment means were not significantly different although the average over the three years shows all phosphate

TABLE 33. TOTAL PHOSPHORUS IN THE OATS SAMPLED AT HEADING TIME AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment(per acre)	Percent Phosphorus 1955	1956	1957	Ave.
No phosphate fertilizer	0.212	0.318	0.236	0.255
10 lbs. P_2O_5(0-20-0)per year	0.230	0.361	0.209	0.267
20 lbs. P_2O_5(0-20-0)per year	0.230	0.369	0.216	0.272
320 lbs. P_2O_5(rock)1951	0.216	0.353	0.214	0.261
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	0.278	0.387	0.225	0.297
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	0.200	0.362	0.238	0.267
L.S.D.(5% level)	n.s.	n.s.	n.s.	n.s.

treated oats with higher phosphorus content than those without phosphate.

Hay. The yearly hay yields would be considered well above average for the area since these yields consisted of only the first cuttings. The second year hay field, after the first cuttings were removed, were field cultivated to control quack grass for the following corn crop. The first and second year hay yields are presented in Tables 34 and 37. The yearly effects of liming on first year hay were not significant. However, the average effect of lime over the six year period was significant statistically at the 1 percent level. Practically, it was of little consequence, since this average yearly increase in yield, due to lime, amounted to only 0.16 tons per acre. With the effect of lime being of such small magnitude and since there were no significant lime interactions, the best method of analyzing phosphate treatment differences is from treatment means over lime levels. The yield data in Table 34 is presented in this manner.

The treatment means were significantly different at the 5 percent level in 1953 and 1957 and at the 1 percent level in 1954. During these years the rock phosphate treatment did not significantly increase yields. The high rate of superphosphate, however, significantly increased yields in 1954 and 1957 and was significantly higher in yield produced in 1953 than the rock phosphate treatment. In 1954, all plots receiving superphosphate had significant increases in yield.

The treatment means over the six year period were significantly different at the 1 percent level. Only the high rate of superphosphate, however, and the combination treatments significantly increased yields. The yields produced by the low rate of superphosphate and the rock phos-

TABLE 34. FIRST CUTTING YIELDS OF FIRST YEAR ALFALFA-BROME AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment(per acre)	Tons per Acre 1952	1953	1954	1955	1956	1957	Ave.
No phosphate fertilizer	0.74	2.30	1.14	0.54	0.46	1.23	1.07
10 lbs. P_2O_5(0-20-0)per year	0.73	2.54	1.60	0.59	0.48	1.10	1.17
20 lbs. P_2O_5(0-20-0)per year	0.79	3.07	1.89	0.55	0.52	1.65	1.39
320 lbs. P_2O_5(rock)1951	0.75	1.94	1.44	0.61	0.61	1.25	1.10
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	0.73	2.65	1.93	0.49	0.62	1.25	1.28
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	0.78	3.57	2.15	0.53	0.60	1.43	1.51
L.S.D.(5% level)	n.s.	0.92	0.41	n.s.	n.s.	0.31	0.17

Analysis of Variance:

Source of Variation	Degrees of Freedom	Mean square	"F" test
Total	287	0.314	1.48 n.s.
Replicates	18	33.45	15.78**
Years(Y)	5	1.89	8.91**
Lime(L)	1	0.310	1.46 n.s.
Error(a)	18	0.212	
Treatment(T)	5	1.444	7.77**
T x L	5	0.164	0.88 n.s.
T x Y	25	0.517	2.78**
T x Y x L	25	0.257	1.38 n.s.
Error(b)	180	0.186	

phate treatments while averaging higher than the plots without phosphate were within experimental error.

The net increase in yield and the effectiveness values for the first year hay are given in Table 35. The net increase in yield produced by the low rate of superphosphate amounted to 0.63 tons per acre or an average effectiveness value over the six years of 21 pounds of hay per pound of P_2O_5 applied. Rock phosphate produced only 1 pound of hay per pound of P_2O_5 applied so the low rate of superphosphate was 21 times more effective. The high rate of superphosphate by the same measure was 34 times more effective than the rock in increasing yields.

The combination treatments produced a considerably greater net increase in yield than that attributable to a simple additive effect of the two materials. However, the relative effectiveness of the combination treatments were only one-third that of the respective superphosphate treatments.

The phosphorus analyses of the 1957 hay crop are given in Table 36. The differences in treatment means were not statistically significant. However, the plots treated with rock phosphate and the combination treatments averaged lower than the respective superphosphate plots.

The second year alfalfa-brome yields averaged approximately one-half ton greater than the first year hay. The effects of liming were also of greater magnitude on the second year hay with the limed treatments producing 0.37 tons per acre higher yield than the unlimed. The data presented in Table 37, however, are treatment means over lime levels. Without significant lime-treatment interactions phosphate treatments are more readily compared in this manner of presentation.

TABLE 35. THE NET INCREASE IN YIELD OF FIRST YEAR HAY IN 6 YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment(per acre)	Pounds P_2O_5 Applied	Tons Increase in Yield	Effectiveness Values Pounds/lb P_2O_5	Effectiveness Values Relative
10 lbs. P_2O_5(0-20-0)per year	60	0.63	21	21
20 lbs. P_2O_5(0-20-0)per year	120	2.06	34	34
320 lbs. P_2O_5(rock)1951	320	0.19	1	1
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	380	1.26	7	7
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	440	2.65	12	12

TABLE 36. TOTAL PHOSPHORUS IN THE FIRST CUTTING OF THE 1957 HAY CROP AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment (per acre)	Percent Phosphorus First year	Percent Phosphorus Second year
No phosphate fertilizer	0.237	0.168
10 lbs. P_2O_5(0-20-0)per year	0.214	0.166
20 lbs. P_2O_5(0-20-0)per year	0.231	0.164
320 lbs. P_2O_5(rock)1951	0.191	0.197
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	0.182	0.199
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	0.207	0.193
L.S.D.(5% level)	n.s.	n.s.

TABLE 37. FIRST CUTTING YIELDS OF SECOND YEAR ALFALFA-BROME AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment(per acre)	1953	1954	Tons per Acre 1955	1957	Ave.
No phosphate fertilizer	2.85	1.52	0.64	1.20	1.55
10 lbs. P_2O_5(0-20-0)per year	3.33	1.50	0.58	1.39	1.70
20 lbs. P_2O_5(0-20-0)per year	3.22	2.11	0.61	1.49	1.86
320 lbs. P_2O_5(rock)1951	3.10	1.35	0.70	1.44	1.65
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	3.22	1.71	0.72	1.43	1.77
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	3.26	2.06	0.78	1.48	1.90
L.S.D.(5% level)	n.s.	0.47	n.s.	n.s.	0.21

Analysis of Variance:

Source of Variation	Degrees of Freedom	Mean square	"F" test
Total	191		
Replicates	12	0.862	2.82*
Years(Y)	3	52.36	171.11**
Lime(L)	1	6.64	21.70**
Y x L	3	1.23	4.03
Errors(a)	12	0.306	
Treatments(T)	5	0.542	3.01*
T x L	5	0.214	1.19 n.s.
T x Y	15	0.205	1.14 n.s.
T x Y x L	15	0.221	1.23 n.s.
Error(b)	120	0.180	

Significant yield differences due to treatment were achieved only in 1954 when the high rate of superphosphate, alone and in combination with rock phosphate, produced a significant yield increase. The yield increase of the combination treatment was no greater than that of the superphosphate alone and, therefore, could be credited to only the superphosphate portion of the combination treatment.

In considering the average over the four years, the high rate of superphosphate and the two combination treatments produced statistically significant yield increases. The yields from the combination treatments, however, were not significantly greater than the respective superphosphate treatment and the benefit in yield of these treatments can be attributed to the superphosphate alone.

The net increase in yield and the effectiveness values for the second year hay are given in Table 38. Since the 1956 crop was not harvested, the superphosphate applied during this year was not included in these data. Generally, the superphosphate was just as effective on the second year hay as on the first year hay, as measured by the pounds of hay produced per pound of P_2O_5 applied. However, relative to the rock phosphate, it was less effective, producing only a 15 times greater yield than the rock. This value is less than that achieved on the first year hay by virtue of the rock phosphate being twice as effective on the second year hay crop.

The phosphorus analyses of the 1957 hay crop are given in Table 36. The rock phosphate and combination treatments produced a higher average phosphorus content than superphosphate and no phosphate. A reverse effect to that observed in the first year hay crop. These differences, however, were not statistically significant.

TABLE 38. THE NET INCREASE IN YIELD OF SECOND YEAR HAY IN FOUR YEARS PRODUCED BY PHOSPHATE FERTILIZATION AT THE GRAND TRAVERSE COUNTY LOCATION

Treatment (per acre)	Pounds P_2O_5 Applied	Tons Increase in Yield	Effectiveness Values Pounds/lb P_2O_5	Effectiveness Values Relative
10 lbs. P_2O_5 (0-20-0) per year	40	0.59	29	15
20 lbs. P_2O_5 (0-20-0) per year	80	1.22	30	15
320 lbs. P_2O_5 (rock) 1951	320	0.38	2	1
320 lbs. P_2O_5 (rock) 1951 plus 10 lbs. P_2O_5 (0-20-0) per year	360	0.87	4	2
320 lbs. P_2O_5 (rock) 1951 plus 20 lbs. P_2O_5 (0-20-0) per year	400	1.37	6	3

Greenhouse Experiments

Fried and Dean (35) have hypothesized that the radiochemical analyses of plants grown on soils receiving applications of fertilizer containing P^{32} can be utilized in calculating the phosphorus supply of the original soil. They have assumed that a plant presented with two sources of phosphorus, that is, soil phosphorus and fertilizer phosphorus, will absorb the phosphorus in direct proportion to the amount available from each source. Experimentally, their hypothesis consists of the application of a standard amount of P^{32} tagged fertilizer to different soils resulting in this phosphorus being absorbed in an inverse relation to that available in each soil. The more phosphorus available in the soil the less P^{32} tagged fertilizer phosphorus in the plant. This relationship is expressed in the following manner:

$$A = \frac{B(1-y)}{y}$$

where A = the amount of soil phosphorus supply.

B = the amount of the fertilizer phosphorus supply.

y = fraction of the phosphorus in the plant derived from the fertilizer.

This A value has been accepted by agronomists as a method of determining phosphorus availability of soils. It is not clear, however, how the time factor of previous applications to the soils of phosphorus materials affects the A value. It is apparently assumed that all previous additions of phosphorus to the soil are soil phosphorus as opposed to that of the immediately applied testing applications of P^{32} tagged material. The A value then, is in fact, a measure of the average availability of all sources of phosphorus contained in the soil, which in most cases, is residual fertilizer. If the A value is a measure of residual fertilizer it could be used in evaluating the effectiveness of rock phosphate in crop growth. This present experiment was devised to utilize this method of soil phosphorus evaluation.

Experimental Procedure

The experiment was divided into two sections by differences in previous soil treatments. The first part consisted of two soils which had applications of rock phosphate just prior to the experiment. The second part consisted of soil taken from the Kalamazoo and Genesee County field experiments in 1953.

In both cases 2 gallons (9000 grams of air-dry soil), was completely mixed with 0.580 grams of radioactive treble (48.5% P_2O_5) superphosphate which added 124 milligrams of phosphorus tagged with P^{32} to each pot. Based on an acre of soil to plow depth weighing 2,000,000 pounds this was equivalent to 128 pounds of treble superphosphate per acre. The soil was then placed in 2 gallon pots and planted to Yorkwin wheat and mammoth clover.

The wheat was harvested six weeks after planting, oven-dried and weighed. The samples were ground in a Wiley-mill and 2 gram samples pelleted for radioactive analyses. Six weeks later the clover was harvested and treated in a like manner.

The standard sample to which the unknown plant samples were compared was made up from the tagged fertilizer material. The following procedure was used: 1.0231 grams of the tagged fertilizer was dissolved in 500 cc of distilled water, then a 10 cc aliquot was mixed into 10 grams of ground alfalfa, the alfalfa oven-dried and then pelleted in 2 gram portions. The 2 gram pellets were checked for uniformity to guarantee a homogeneous standard. Each standard contained, therefore:

$$\frac{1023.1 \text{ mgm}}{500 \text{ cc}} \times 10 \text{ cc} \times \frac{2 \text{ gr}}{10 \text{ gr}} \times .485 \; P_2O_5 = 1.985 \text{ mgm } P_2O_5$$

The activity of this amount of standard P_2O_5 was compared to that of the plant samples. Since the activity of the samples was in direct proportion to the amount of fertilizer phosphorus contained, the amount of fertilizer phosphorus in the plant was readily determined.

Availability of New Application of Rock Phosphate

Twenty four 2 gallon glazed clay pots were filled with air-dried and screened Oshtemo loamy sand and an equal number with a Miami loam. Three months prior to planting, lime was added to twelve pots of each soil. Precipitated $CaCO_3$ at an equivalent rate of one-half ton per acre was added to the Oshtemo and at one ton per acre to the Miami. All soils were watered with distilled water and kept moist for two months, when they were allowed to dry.

At this time, one month prior to planting, eight pots of each soil, four limed and four unlimed, were thoroughly mixed with an equivalent rate of 1000 pounds per acre of rock phosphate. All other pots were just mixed to assure that the only variable at this time was the added rock phosphate. The soils were again watered and kept moist until planting time when they were allowed to dry.

At the time of planting, another eight pots of each soil, four limed and four unlimed, were mixed with the equivalent rate of 1000 pounds per acre of rock phosphate. In addition, the radioactive treble superphosphate was mixed into all pots, as previously described. Therefore, there were four pots or replicates each, of Miami and Oshtemo, in a limed and unlimed condition, with the following treatments:

1. No rock phosphate
2. 1000 pounds per acre of rock phosphate applied at time of planting
3. 1000 pounds per acre of rock phosphate applied one month ahead of planting.

These pots were arranged on the greenhouse benches in a randomized block design. The liming only slightly affected the pH of the Oshtemo raising it from pH 5.3 to pH 5.5. The pH of the Miami of less acidity originally, was more greatly affected, from pH 6.0 to pH 6.5. Spurway "reserve" soil tests for phosphorus on the original soil showed medium phosphorus (45 pounds per acre) in the Oshtemo and low phosphorus (13 pounds per acre) in the Miami. The potassium levels in both soils amounted to 140 pounds of potassium per acre.

The yield of the winter wheat, the plant analyses, and the A values derived are given in Table 39. Little significant difference was noted between the phosphate treatments. However, differences due to soil were highly significant, except in yield per pot, which were not significantly different. The Miami loam gave significantly lower A values than the Oshtemo loamy sand and significantly higher values in plant phosphorus. The lower content of available soil phosphorus in the Miami as compared to the Oshtemo was also indicated in the Spurway "reserve" test.

The yield of the second crop, clover, the plant analyses and the A values derived are presented in Table 40. The same highly significant differences between soil types were observed as in the case of the wheat,

TABLE 39. THE YIELD OF GREENHOUSE GROWN WHEAT, PERCENT PHOSPHORUS IN THE PLANT AND A VALUES OF THE SOILS

Soil	Treatment	Yield Gr/Pot	Plant P_2O_5 Total Percent	Plant P_2O_5 Percent from P^{32}	A Value Mgm/Pot
	No phosphate	9.3	0.230	54.1	112
Miami	1000 lbs. rock phosphate/ac at planting	9.3	0.216	51.4	95
	1000 lbs. rock phosphate/ac 1 mo. before	9.9	0.241	58.0	96
	No phosphate	9.0	0.167	21.4	464
Oshtemo	1000 lbs. rock phosphate/ac at planting	10.8	0.149	20.8	487
	1000 lbs. rock phosphate/ac 1 mo. before	9.2	0.161	20.3	499
L.S.D. with soils(5% level)		n.s.	n.s.	n.s.	n.s.

TABLE 40. THE YIELD OF GREENHOUSE GROWN MAMMOTH CLOVER, PERCENT PHOSPHORUS IN THE PLANT AND A VALUES OF THE SOILS.

Soil	Treatment	Yield Gr/Pot	Plant P_2O_5 Total Percent	Plant P_2O_5 Percent from P^{32}	A Value Mgm/Pot
	No phosphate	9.7	0.370	30.7	282
Miami	1000 lbs. rock phosphate/ac at planting	9.7	0.424	31.4	307
	1000 lbs. rock phosphate/ac 1 mo. before	9.3	0.376	30.4	294
	No phosphate	5.0	0.763	18.5	622
Oshtemo	1000 lbs. rock phosphate/ac at planting	5.4	0.745	12.7	864
	1000 lbs. rock phosphate/ac 1 mo. before	5.4	0.871	13.2	833
L.S.D. within soils (5% level)		n.s.	n.s.	n.s.	125

but in addition the yield differences were also significant at the 1 percent level, with lower yields observed on the Oshtemo. The effects of the phosphate treatments in increasing the A value on the Miami loam were not significant. However, the rock phosphate did increase the A values significantly with the Oshtemo loamy sand. Yield increases were also associated with this increased A value but were well within the realm experimental error.

Residual Effect of Treatments on Soils from the Field Plots

After the corn was harvested in 1953 from the Kalamazoo and Grand Traverse County field experiments, proportionate amounts of the plow layer were taken from each plot and composited by treatment. This soil was air-dried, screened (4 mesh) and placed in 2 gallon pots, four replicates per treatment. At the time of planting the radioactive treble superphosphate was mixed into all pots, as previously mentioned. The experimental design employed was similar to that utilized in the field.

Kalamazoo County. The yield of wheat, plant analyses and A values derived are presented in Table 41. These data are given as treatment means over lime levels.

The only treatment significantly increasing yields was the combination treatment of rock phosphate plus the low rate of superphosphate. In respect to the phosphorus content of the plant this treatment produced a lower phosphorus percentage than the treatment without phosphate although to a non-significant degree. The rock phosphate treatment and the rock phosphate plus the high rate of superphosphate significantly increased the phosphorus content.

TABLE 41. THE YIELD OF GREENHOUSE GROWN WHEAT, PERCENT PHOSPHORUS IN THE PLANT AND A VALUES OF THE SOILS FROM THE KALAMAZOO COUNTY LOCATION

Residual Treatment(per acre)	Total P_2O_5 Applied	Yield Gr/Pot	Plant P_2O_5 Total Percent	Plant P_2O_5 Percent from P^{32}	A Value Mgm/Pot
No phosphate fertilizer	0	6.2	0.593	44.4	166
10 lbs. P_2O_5(0-20-0)per year	30	5.7	0.658	37.5	210
20 lbs. P_2O_5(0-20-0)per year	60	6.0	0.706	35.6	229
320 lbs. P_2O_5(rock)1951	320	5.8	0.719	36.3	226
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	350	7.2	0.511	39.1	201
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	380	5.4	0.793	34.2	248
L.S.D.(5% level)		0.8	0.120	6.1	49

Wheat grown on the soil from the field plots without phosphate utilized the greatest percentage of tagged fertilizer phosphorus, indicating less available phosphorus in this soil. This was borne out by the A values. This soil had a significantly lower A value than where treated with rock phosphate, the high rate of superphosphate and the combination of the two. The soil treated with the low rate of superphosphate alone or with rock phosphate exhibited higher A values than the soil without phosphate but was not statistically significant.

The observations presented for wheat are also given for the following mammoth clover crop in Table 42. The clover being one crop considered a "strong feeder" on less available forms of phosphorus produced higher yields on the soils containing the rock phosphate. However, only the soils with rock phosphate alone produced a statistically significant increase in yield.

The phosphorus content of the plant material was not significantly affected by treatment, however, the lowest amount of tagged fertilizer phosphorus was observed in plants grown on the soils treated with rock phosphate. The A values for these soils was considerable higher than where rock phosphate was not used but these values were within experimental error.

The fact that the A values of the soils were higher for the clover than for the wheat was a probable result of two effects. First, the amount of radioactive phosphorus was reduced for the clover crop by that removed in the wheat. This would result in the residual or A value phosphorus being in greater proportion to the P^{32} for the clover. Secondly, and probably more important, the clover utilized more insoluble forms of

TABLE 42. THE YIELD OF GREENHOUSE GROWN MAMMOTH CLOVER, PERCENT PHOSPHORUS IN THE PLANT AND A VALUES OF THE SOILS FROM THE KALAMAZOO COUNTY LOCATION

Residual Treatment (per acre)	Total P_2O_5 Applied	Yield Gr/Pot	Plant P_2O_5 Total Percent	Plant P_2O_5 Percent from P^{32}	A Value Mgm/Pot
No phosphate fertilizer	0	4.3	0.525	29.0	305
10 lbs. P_2O_5(0-20-0)per year	30	4.5	0.577	28.4	322
20 lbs. P_2O_5(0-20-0)per year	60	4.0	0.566	29.8	305
320 lbs. P_2O_5(rock)1951	320	6.0	0.528	26.2	359
320 lbs. P_2O_5(rock)1951 plus 10 lbs. P_2O_5(0-20-0)per year	350	4.8	0.554	25.1	390
320 lbs. P_2O_5(rock)1951 plus 20 lbs. P_2O_5(0-20-0)per year	380	4.9	0.574	26.5	384
L.S.D.(5% level)		1.2	n.s.	n.s.	n.s.

of phosphorus than wheat and would, therefore, show a greater quantity of available phosphorus. This fact is evidenced by the higher A values of the soils treated with rock phosphate with clover as compared to those without rock phosphate and the small differences in A values between these soils when wheat was grown.

Genesee County. The yield of wheat, plant analyses and A values derived are presented in Table 43. These data are given as treatment means over lime levels.

Less consistency is noted in these data than with the Kalamazoo County soils. Yields of crops produced by the rock phosphate and the low rate of superphosphate were significantly greater than from the soils without phosphate. Yet the yield from these materials combined was significantly lower than from the soils without phosphate.

A greater amount of tagged fertilizer phosphorus was utilized by the wheat in these experiments when compared to the soil from the Kalamazoo County experiments. This would indicate a lower available phosphorus content in the Genesee County soils. This conclusion is corroborated by the soil tests (P_1) of the field experiments which show considerably more available phosphorus in the Kalamazoo County soils. The A values are accordingly lower in the Genesee County soils, with little difference between treatments, although the low rate of superphosphate resulted in a significantly lower A value than in the soil without phosphate.

The mammoth clover data, given in Table 44, are summarized as treatment means over lime levels. These data, as with the wheat, are of little significance. In relation to the soil without phosphate the phosphate treatments did not significantly affect phosphorus content nor the A value. As with the Kalamazoo County soils the clover gave higher A values than the wheat.

TABLE 43. THE YIELD OF GREENHOUSE GROWN WHEAT, PERCENT PHOSPHORUS IN THE PLANT AND A VALUES OF THE SOILS FROM THE GENESEE COUNTY LOCATION

Residual Treatment(per acre)	P_2O_5 Applied	Yield Gr/Pot	Plant P_2O_5 Total Percent	Plant P_2O_5 Percent from P^{32}	A Value Mgm/Pot
No phosphate fertilizer	0	9.3	0.570	46.5	153
10 lbs. P_2O_5(0-20-0)per year	40	10.9	0.521	53.5	111
20 lbs. P_2O_5(0-20-0)per year	80	9.4	0.552	48.7	135
320 lbs. P_2O_5(rock)1950	320	11.6	0.510	50.3	126
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	360	7.9	0.592	43.2	171
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	400	8.6	0.587	45.6	152
L.S.D.(5% level)		1.0	n.s.	6.5	35

TABLE 44. THE YIELD OF GREENHOUSE GROWN MAMMOTH CLOVER, PERCENT PHOSPHORUS IN THE PLANT AND A VALUES OF THE SOILS FROM THE GENESEE COUNTY LOCATION

Residual Treatment(per acre)	Total P_2O_5 Applied	Yield Gr/Pot	Plant P_2O_5 Total Percent	Plant P_2O_5 Percent from P^{32}	A Value Mgm/Pot
No phosphate fertilizer	0	8.0	0.443	34.0	250
10 lbs. P_2O_5(0-20-0)per year	40	7.1	0.477	36.2	226
20 lbs. P_2O_5(0-20-0)per year	80	7.5	0.378	39.8	202
320 lbs. P_2O_5(rock)1950	320	8.9	0.393	37.0	225
320 lbs. P_2O_5(rock)1950 plus 10 lbs. P_2O_5(0-20-0)per year	360	6.9	0.496	31.8	279
320 lbs. P_2O_5(rock)1950 plus 20 lbs. P_2O_5(0-20-0)per year	400	7.9	0.475	32.2	268
L.S.D(5% level)		n.s.	0.075	n.s.	53

SUMMARY AND CONCLUSICNS

The results of the four field experiments are summarized in Table 45. These data are given as the relative effectiveness of superphosphate over rock phosphate. The A values, also determined, did not give as complete a comparison. These effectiveness values presented in Table 45 are averages of those of both rates of superphosphate which were given earlier. It is felt that the differences in effectiveness between these rates is well within experimental error. The only observations with a wide difference between rates are those of the wheat crop from Iosco County and the first year hay from Grand Traverse County. The other ten observations ranged only a few units apart.

Since these relative effectiveness values are derived from the net increase in yield and the total P_2O_5 application over the duration of each experiment they are actually the average effectiveness over the time period of the investigation. As such, these values are of greater importance in evaluating the effectiveness of rock phosphate than differences in average yield or comparisons of one years effects which have been the usual methods listed in the literature.

The corn crops did not give yield responses to the applied rock phosphate. In estimating the value of rock phosphate in a crop rotation, therefore, the corn crop must be considered as non benefiting.

The oat crop did give small increases in yield from the applied rock phosphate, however, superphosphate ranged from 6 to 26 times more effective. Generally, superphosphate averaged 15 times greater in effectiveness than the rock phosphate in increasing yield of oats.

TABLE 45. THE RELATIVE EFFECTIVENESS OF SUPERPHOSPHATE OVER ROCK PHOSPHATE PER POUND OF APPLIED P_2O_5

Location	P1 test	Corn	Small Grain	First Year Hay	Second Year Hay
Kalamazoo	v.high	n.r.p.+	6	5	7
Genesee	low	n.r.r.	20	6	2.5
Iosco	medium	n.r.p.	26	11	8
Grand Traverse	high	n.r.r.	9	27	15
Average			15	12	8

\+ n.r.p. = no response to phosphate
n.r.r. = no response to rock phosphate

The first year hay crops exhibited a similar superiority of superphosphate to rock phosphate. The range of effectiveness of superphosphate was 5 to 27 times greater in increasing yields. As an average superphosphate was 12 times more effective than rock phosphate per pound of P_2O_5 applied.

The second year hay showed a greater response to rock phosphate than the previous crops. However, the effectiveness of superphosphate was still 2.5 to 15 times greater. These values averaged 8 times greater over the four experiments.

With the best average effectiveness of rock phosphate at one-eighth that of superphosphate, rock phosphate does not belong in the fertilization program of rotation crops on the farms of Michigan. On the basis of superphosphate priced at $50.00 a ton, or 12.5 cents per pound of P_2O_5, rock phosphate would have to sell at 1.6 cents per pound or $10.56 a ton, at the most, to be an equivalent buy. With an average effectiveness of one-twelfth that of superphosphate as a fertilizer for small grains and first and second year hay, rock phosphate would have to sell at 1 cent per pound or $6.60 a ton to be equivalent.

LITERATURE CITED

1. Ames, J. W. and K. Kitsuta. Availability of rock phosphate as indicated by phosphorus assimilation by plants. Jour. Amer. Soc. Agron. 24:103-122. 1932.

2. Armiger, W. H. and M. Fried. The plant availability of various sources of phosphate rock. Proc. Soil Sci. Soc. Amer. 21(2):183-188. 1957.

3. Bachtell, M. A. and G. W. Volk. Rock phosphate results inferior to those of superphosphate. Ohio Agr. Exp. Sta. Farm and Home Res. Bull. 271:59-60. 1951.

4. Barber, Stanley A. Report on regional rock phosphate evaluation in Indiana. Purdue Agr. Exp. Sta. Agron. Dept. Mimeo. AY no. 81. June, 1947.

5 Bartholomew, R. D. The unavailability of phosphorus in rock phosphate to some southern crops. Journ. Amer. Soc. Agron. 20:913-920. 1928.

6. ________________. Fluorine, its effect on plant growth and its relation to the availability to plants of phosphorus in phosphate rock. Soil Sci. 40:203-217. 1935.

7. ________________. Availability of phosphate rocks in soils of varying acidity. Jour. Amer. Soc. Agron. 29:293-298. 1937.

8. Bauer, F. C. The relation of organic matter and feeding power of plants to the utilization of rock phosphate. Soil Sci. 12;12-41.1921.

9. __________, A. L. Lang, C. J. Badger, L. B. Miller, C. H. Farnham, P. E. Johnson, L. T. Marriott and M. H. Nelson. Effects of soil treatment on soil productivity. Illinois Agr. Exp. Sta. Bull. 516. 1945.

10. Bennett, O. L., L. E. Ensminger and R. W. Pearson. The availability of phosphorus in various sources of rock phosphate as shown by greenhouse studies. Proc. Soil Sci. Soc. Amer. 21(5):521-524. 1957.

11. Bray, R. H. Phosphorus availability and crop response. Proc. Soil Sci. Soc. Amer. 11:215-221. 1937.

12. Bridgford, Ray O. and C. O. Rost. Comparative value of rock phosphate and superphosphate as fertilizers. Submitted for publication. Minn. Agr. Exp. Sta. 1958.

13. Brown, B. E. and A. Hawkins. A comparison of colloidal phosphate, rock phosphate and superphosphate as sources of P in potato fertilizer in Aroostook County, Maine. Am. Fertilizer 100(8):5-7. 1949.

14. ________________ and K. D. Jacob. Greenhouse and field tests comparing colloidal phosphate, phosphate rock and superphosphate as sources of phosphorus for various crop plants. Am. Fertilizer 101(13):7-10. 1944.

15. ________________, J. A. Chucka, A. Hawkins and J. E. Campbell. Field comparisons of colloidal phosphate, rock phosphate and superphosphate as sources of phosphorus in potato fertilizers. Am. Potato Jour. 21:241-249. 1944.

16. ________________ and K. D. Jacob. Greenhouse pot culture tests on rock phosphates as sources of phosphorus for plants. Am. Fertilizer 102(1):11-12. 1945.

17 Burlison, W. L. Availability of mineral phosphates for plant nutrition. Jour. Agr. Res. 6(13):485-514. 1916.

18. Caldwell, A. G., F. L. Fisher and R. H. Weihing. The effect of lime and phosphate on the yield of pasture at three Texas stations. Unpublished data. Texas Agr. Exp. Sta. Project 573. 1955.

19. ______________, A Hustrulid and F. L. Hammers. Residual availability in the soil of various sources of phosphate as measured by plant absorption of P^{32} and by soil test. Proc. Soil Sci. Soc. Amer. 20 (1):25-28. 1956.

20. ______________, Hugo Velasco and Curtiss L. Godfrey. Effect of time, soil type and source of phosphorus on the extractability of applied phosphorus. Abstract of paper presented to the Agron. Sec., South. Agr. Workers. February 5, 1957.

21. Caro, J. H. and W. L. Hill. Characteristics and fertilizer value of phosphate rock from different fields. Jour. Agr. Food Chem. 4:684-687. 1956.

22. Cheaney, R. L., Ralph M. Weihing and R. Norton Ford. The effect of various rates and frequencies of application of rock and superphosphate on the yield and composition of forage on a Lake Charles clay loam soil. Proc. Soil Sci. Soc. Amer. 20(1):66-68. 1956.

23. Conner, S. C. and J. E. Adams. Availability of Tennessee raw rock phosphate in relation to fineness and other factors. Jour. Amer. Soc. Agron. 18:1103-1107. 1926.

24. Cooke, George W. The agricultural value of phosphate fertilizers which economize in the use of sulfuric acid. European Prod. Agency. Org. European Econ. Coop. Project No. 162.

25. Dean, L. A. and M. Fried. Chap. II. Soil-plant relationships in the phosphorus nutrition of plants. Pierre, W. H. and A. G. Norman, Editors. Soil and Fertilizer Phosphorus. Academic Press Inc., New York, 1953. 492 pp.

26. DeTurk, E. E. 39th Ann. Rep. Illinois Agr. Exp. Sta. p. 23. 1926.

27. ___________. The problem of phosphate fertilizers. Illinois Agr. Exp. Sta. Bull. 484. 1942.

28. Dickman, S. R. and E. E. DeTurk. Response of young corn plants to inorganic phosphate differing in solubility:1. The effect of phosphorus absorption from rock phosphate on the composition and dry weight of corn at three periods. Proc. Soil Sci. Soc. Amer. 5:213-219. 1940.

29. Dunton, E. M. Jr. A study of the effectiveness of four phosphorus carriers on increasing soluble soil phosphorus and on crop growth with a virgin Sassafras sandy loam. Virginia Truck Exp. Sta. Project Report No. (Soils 14-B, 1953).

30 Dymond, G. C. The increase of available phosphate in rock phosphate by composting. Proc. Ann. Cong. S. African Sugar Tech. Assoc. 25: 84-85. 1951.Seen in abstract only. Chem. Abst. 46:3197:. 1952.

31. Ensminger, L. E. Response of crops to various phosphate fertilizers. Alabama Agr. Exp. Sta. Bull. 270. 1950.

32. _______________ and R. W. Pearson. Residual effect of various phosphates as measured by yields, P^{32} uptake and extractable phosphorus. Proc. Soil Sci. Soc. Amer. 21(1):80-84. 1957.

33. Finn, B. J., R. L. Cook and C. M. Harrison. Comparison of rock phosphate to superphosphate for oats and alfalfa on three podsolized soils of eastern Canada. Jour. Amer. Soc. Agron. 49:465-468. 1957.

34. Fried, M. and Arnold J. MacKenzie. Rock phosphate studies with neutron irradiated rock phosphate. Proc. Soil Sci. Soc. Amer. 14:226-231. 1949.

35. ________ and L. A. Dean. A concept concerning the measurement of available soil nutrients. Soil Sci. 73:263-271. 1952.

36. ________. The feeding power of plants for phosphates. Proc. Soil Sci. Soc. Amer. 17(4):357-359. 1953.

37. Green, J. Phosphate investigations in Montana. Montana Agr. Exp. Sta. Bull. 356. 1938.

38. Gustafson, A. F. Handbook of Fertilizers. 4th edition. Orange Judd Pub. Co., Inc., New York. 1949. 172 pp.

39. Hendricks, S. B., W. L. Hill, K. D. Jacob and M. E. Jefferson. Structural characteristics of apatite-like substances and composition of phosphate rock as determined from microscopical and X-ray diffraction examinations. Ind. Eng. Chem. 23:1413-1418. 1931.

40. Hill, Elton, B and Russell G. Mawby. Types of farming in Michigan. Mich. Agr. Exp. Sta. Spec. Bull. 206(2nd Rev.). 1954.

41. Hopkins, C. G. Phosphates and honesty. Illinois Agr. Exp. Sta. Circ. 186. 1916.

42. Jacob, K. D., W. L. Hill, H. L. Marshall and D. S. Reynolds. The composition and distribution of phosphate rock with special reference to the United Stated. U.S.D.A. Tech. Bull. 364. 1933.

43. ________. Chap V. Phosphate resources and processing facilities. Jacob, K. D., Editor. Fertilizer Technology and Resources. Academic Press, Inc. New York, 1953. 454 pp.

44. Jones, Randall J. and Howard T. Rogers. New fertilizers and fertilizer practices. Norman, A. G., Editor. Advances in Agronomy, I. Academic Press Inc. New York. 1949. 439 pp.

45. Jones, U. S. Availability of phosphorus in rock phosphate as influenced by potassium and nitrogen salts, lime and organic matter. Jour. Amer. Soc. Agron. 40:765-770. 1948.

46. Joos, L. L. and C. A. Black. Availability of phosphate rock as affected by particle size and contact with bentonite and soil of different pH values. Proc. Soil Sci. Soc. Amer. 15:69-75. 1950.

47. Karovkin, M. A. Increasing the effectiveness of rock phosphate under the influence of sod culture. Sovet. Agron. 10(9):83-84. 1952. Seen in abstract only. Chem. Abst. 47:5059 b. 1953.

48. ________, Utilization of rock phosphate flour for organo-mineral composts. Sovet. Agron. 10(12):57-60. 1952. Seen in abstract only. Chem. Abst. 47:5059c. 1953.

49. Kentucky, University of. Summary of results of experiments at Western Kentucky Substation, 1927-1949. Kentucky Agr. Exp. Sta. 1950.

50. Koshel'kov, P. N. The neutralizing capacity of ground rock phosphate. Pochvovedenie(U.S.S.R.) 1950:688-697. Seen in abstract only. Chem. Abst. 45:4392 a. 1951.

51. Lang, A. L. First things first in soil fertility. Better crops with Plant Food Mag. Nov. 1945.

52. ________. The use of rock phosphate in Illinois. Proc. Soil Sci. Soc. Fla. 10:47-67. 1950.

53. ________. Rock phosphate for direct application. A natural in soil conservation work plans. Jour. Soil Water Cons. Jan. 1953.

54. ________. Rock phosphate. Farm Quart. Spring 1953.

55. Larson, H. W. E. and G. O. Baker. A preliminary report on the relative value of various phosphate fertilizers for southern Idaho soil conditions. Idaho Ext. Bull. 120. 1939.

56. Lawton, Kirk, C. G. Apostolakis, R. L. Cook and W. L. Hill. Influence of particle size, water solubility and placement of fertilizer on the nutrient value of phosphorus in mixed fertilizers. Soil Sci. 82:465-476. 1956.

57. Long, O. H. Rock phosphate or superphosphate? Tenn. Agr. Expt. Sta. Res. Report 1955.

58. McKelvey, V. E., J. B. Cathcart, Z. S. Altschuler, R. W. Swanson and Katherine L. Buck. Chap. XI. Domestic phosphate deposits. Pierre, W. H. and A. G. Norman, Editors. Soil and Fertilizer Phosphorus. Academic Press Inc., New York. 1953. 492 pp.

59. McLean, E. O., D. A. Brown and C. A. Hawkins. Comparative evaluation studies on rock and superphosphate. Arkansas Agr. Exp. Sta. Bull. 528. Nov. 1952.

60. ___________, and J. E. Hoelscher. Factors affecting yields and uptake of phosphorus by different crops:I. Previous applications to the soil of rock phosphate and superphosphate. Soil Sci. 78(6) 453-462. 1954.

61. ___________. Field evaluation studies of rock and superphosphate. Arkansas Agr. Exp. Sta. Mimeo. Series, No. 41. Feb. 1956.

62. ___________. Factors affecting yields and uptake of phosphorus by different crops: II. Rock phosphate and superphosphate, separate and in combination under extended cropping. Soil Sci. 82(3):181-192. 1956.

63. Mehring, A. L., J. Richard Adams and K. D. Jacob. Statistics on fertilizer and liming materials in the United States. U.S.D.A., A.R.S. Stat. Bull. 191. 1957.

64. Merrill, L. H. Ability of different plants to get phosphoric acid from crude phosphates. Maine Agr. Exp. Sta. 7th Ann. Report 1891.

65. Michigan State University. Colloidal phosphate. Soil Sci. Dept. Mich. Ext. Mimeo. March, 1956.

66. Michigan State University. Fertilizer recommendations for Michigan Crops. Soil Sci. Dept. Mich. Ext. Bull. 159(revised). 1957.

67. Miller, Edwin C. Plant Physiology. 2nd Edition. McGraw Hill Book Co., Inc. New York. 1938.

68. Minnesota, University of. Phosphate facts. Minn. Ext. Ser., Minn. Agr. Exp. Sta. Misc. Paper No. 741.

69. Mooers, C. A. The comparative values of different phosphates. Tenn. Agr. Exp. Sta. Bull. 41. 1929.

70. Moschler, W. W. Experiments with rock phosphate fertilizers in Virginia. Virginia Agr. Exp. Sta. Res. Report No. 9. July 1957.

71. ____________ and George R. Jones. Applying rock phosphate prior to seeding increases availability. Written communication 1958.

72. ____________, R. D. Krebs and S. S. Obenshain. Availability of residual phosphorus from long time rock phosphate and superphosphate applications to Groseclose silt loam. Proc. Soil Sci. Soc. Amer. 21(3):293-295. 1957.

73. Mulvery, R. R. Sources of phosphate for field crops grown on Crosby silt loam soil. Purdue Agr. Exp. Sta. Mimeo. AY No. 81. June, 1947.

74. Murkóck, J. T. and W. A. Seay. The availability to greenhouse crops of rock phosphate phosphorus and calcium in superphosphate-rock phosphate mixtures. Proc. Soil Sci. Soc. Amer. 19(2):199-203. 1955.

75. Natural Phosphorus Research Work Group. Summary of phosphorus research in the United States relating to soils and fertilizers. U.S.D.S. Bur. Plant Ind., Soils and Agr. Engin. Beltsville, Maryland. 1950.

76. National Plant Food Institute. Our land and its care. Washington, D.C. 1956.

77. Neller, J.R. Effect of Sulfur and gypsum additions on availability of rock phosphate phosphorus in Leon fine sandy. Soil Sci. 82(2): 129-134. 1956.

78. _________ and F. D. Bartlett. Effect of particle size on availability and mobility of fused tricalcium phosphate and rock phosphate compared with other phosphates in contrasting soil types. Proc. Soil Sci. Soc. Amer. 21(2):189-192. 1957.

79. Noll, C.T. and C. J. Irvin. Field tests of phosphate fertilizers. Penn. Agr. Exp. Sta. Bull. 423. 1942.

80. Odland, T. E. and T. R. Cox. Field experiments with phosphate fertilizers. Rhode Island Agr. Exp. Sta. Bull. 281. 1942.

81. Ohio State University. Handbook of Ohio experiments in agronomy. Ohio Agr. Exp. Sta. Book Series B-3. Nov. 1957.

82. Olsen, Sterling R. Chap. IV. Inorganic phosphorus in alkaline and calcareous soils. Pierre, W. H. and A. G. Norman, Editors. Soil and Fertilizer Phosphorus. Academic Press Inc., New York. 1953. 492 pp.

83. Pierre, W. H. Phosphorus deficiency and soil fertility. Soils and Men. U.S.D.A. Yearbook of Agriculture 1938. Washington, D. C. 1232 pp.

84. Pirsson, Louis and Adolph Knopf. Rocks and Rock Minerals. 3rd edition. John Wiley and Sons, Inc. New York. 1956. 349 pp.

85. Pittman, D. W. and D. W. Thorne. Fertilizers for Utah soils. Utah Agr. Exp. Sta. Circ. 116. 1941.

86. Porter, J. A., P. J. Rood and E. D. Longnecker. Lime and its use. Mich. Ext. Bull. 314. 1955.

87. Purdue University. Results of phosphate comparisons. Purdue Agr. Exp. Sta. Mimeo. AY 9 (rev.)April. 1951.

88. Purdue University. Progress report on field plot comparisons of phosphate materials in Indiana. Purdue Agr. Exp. Sta. Mimeo. AY 8. March 1952.

89. Roberts, George, J. F. Freeman and E. J. Kinney. Soil management Experiments. Univ. Kentucky Bull. 397. 1939.

90. Rogers, H. T., R. W. Pearson and L. E. Ensminger. Chap.VII. Comparative efficiency of various phosphate fertilizers. Pierre, W. H. and A. G. Norman, Editors. Soil and Fertilizer Phosphorus. Academic Press Inc. New York. 1953. 492 pp.

91. Roosevelt, F. D. Message to Congress. May 20, 1938.

92. Rorty, James. Phosphorus: bottleneck of the Worlds hunger. Harper's Magazine. 1158(Nov.):472-480. 1946.

93. Rost, C. O. and Paul M. Burson. Comparative trials with rock phosphate and superphosphate in Minnesota. Minn. Agr. Ext. Div. Soil Series No. 18. January 1947.

94. Russel, E. W. Soil Conditions and Plant Growth. 8th edition. Longmans, Green and Co. London, New York, Toronto. 1950.

95. Salter, Robt. M. and E.E. Barnes. The efficiency of soil and fertilizer phosphorus as affected by soil reaction. Ohio Agr. Exp. Sta. Bull.553. 1935.

96. Samoilov, I. I. Increasing the effectiveness of rock phosphate flour. Koklady Vsesoyuz. Akad. Sel'skokhoz. nauk im. V. I. Lenina 17 (4): 3-10. 1952. Seen in abstract only. Chem. Abst. 47:4539a. 1953.

97. Sauchelli, Vincent. Manuel in Phosphates in Agriculture. (revised Edition). Davison Chem. Corp. Baltimore, Maryland. 1951.

98. Smith, F. W., F. E. Davison and V. H. Peterson. Soil fertility investigations at Columbus experiment field, 1924-54. Kansas Agr. Exp. Sta. Bull. 372. July, 1955.

99. Smith, R. S. The differential response of two soil associations to rock phosphate. Jour. Amer. Soc. Agron. 42(10):415-497. 1950.

100. Soil Survey Staff. Soil Survey Manuel. U.S.D.A. Handbook No. 18. Washington, D.C. August, 1951. 503 pp.

101. Stanberry, C. O. The behavior of phosphorus in an alkaline irrigated soil in Washington. Proc. Soil Sci. Soc. Amer. 13: 205-212.1948.

102. Toevs, John L. and G. Orien Baker. Progress report of phosphate and other fertilizer investigations at the Aberdeen Branch Station. Idaho Agr. Exp. Sta. Bull. 230. 1939.

103. Truog, E. Factors influencing the availability of rock phosphate. Wisc. Agr. Exp. Sta. Bull. 20. 1912.

104. ________. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wisc. Agr. Exp. Sta. Bull. 41. 1929.

105. ________. Value of so-called colloidal phosphate or soft phosphate containing colloidal clay. Univ. of Wisc. Soils Dept. Mimeo., May 10, 1947.

106. Van Hise, C. R. Preservation of the phosphates and the conservation of the soil. Amer. Acad. Polit. Soc. Sci. Ann. 33(3):215-226. 1909.

107. Volk, Garth W. Availability of rock and other phosphate fertilizers as influenced by lime and form of nitrogen fertilizer. Jour. Amer. Soc. Agron. 36:46-56. 1944.

108. ____________. Response to residual phosphorus of cotton in continuous culture. Jour. Amer. Soc. Agron. 37:330-340. 1945.

109. Volkerding, C.C. and T.E. Stoa. Is rock phosphate a good fertilizer for North Dakota? North Dakota Agr. Exp. Sta. Bimonthly Bull. 10(1):13-17. 1947.

110. Weeks, M. E. and H. F. Miller. The residual effects of phosphates used on long time field experiments. Proc. Soil Sci. Soc. Amer. 13:102-107. 1948.

111. Weihing, Ralph M., A. G. Caldwell and J. F. Fudge. Phosphate sources in pasture production on a Bernard clay loam. Jour. Amer. Soc.Agron. (in press).

112. Weldon, M. D. Rock phosphate and colloidal phosphate for use as fertilizer. Univ. of Nebraska. Agron. Dept., Ext. Ser. form letter. 1958.

113. Whiteside, E. P., I. F. Schneider and R. L. Cook. Soils of Michigan. Mich. Agr. Exp. Sta. Spec. Bull. 402. 1956.

114. Wiancko, A. T. and S. D. Conner. Acid phosphate vs. raw rock phosphate as fertilizer. Indiana Agr. Exp. Sta. Bull. 187. 1916.

115. Williams, E. G. Phosphate fixation and availability. Jour. Sci. Food Agr. 8:244-248. 1950.

116. Willis, W. P. Jr. and F. M. Harrington, Phosphate investigations in Montana. Montana Agr. Exp. Sta. Bull. 369. 1939.

117. Wisconsin, University of. Solubility of rock phosphate at different pH levels or in soils of varying reaction. Soil Sci. Dept. Ext. Mimeo. Jan. 24, 1951.