THE EFFECT OF GRANULATION AND PLACEMENT ON THE RELATIVE UPTAKE OF PHOSPHORUS FROM SUPERPHOSPHATE BY BEANS AND WHEAT AS MEASURED BY TRACER TECHNIQUES

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

James A. Vomocil

1951

This is to certify that the

thesis entitled

The Effect of Granulation and Placement on the Relative Uptake of Phosphorus from Superphosphate by Beans and Wheat as Measured by Tracer Techniques

presented by

James A. Vomocil

has been accepted towards fulfillment of the requirements for

Master of Science degree in Soil Science

L. M. Turk
Major professor

Date November 21, 1951

O-169

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by

JAMES A. VOMOCIL

A THESIS

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

MASTER OF SCIENCE

Department of Soil Science

1951

THESIS

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Dr. K. Lawton for his helpful suggestions and guidance throughout the progress of the work.

He is also indebted to Dr. E. Kawin for advice and assistance in the radioisotope measurement procedure.

Grateful acknowledgement is also due to Dr. R.L. Cook for taking photographs and to Mr. P. Coleman for taking and preparing microphotographs.

The writer extends gracious acknowledgement to Dr. L.M. Turk for his criticism of the manuscript.

He is indebted to the graduate council of Michigan State College for the granting of the assistantship which made the completion of this work possible.

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INTRODUCTION

The consumers of fertilizers are concerned with the nutrient supplying power of a fertilizer material. The nutrient supplying power of a fertilizer is determined to a large extent by its composition but is also dependent upon the availability of the nutrient elements to the crop grown under field conditions. This availability may be considered the "efficiency" of the nutrient source. Hence, in fertility studies the problem of evaluating the relative efficiency of fertilizer materials is an important one. Methods of improving the efficiency of the materials which supply the nutrients necessary for the production of crops are continually being proposed.

The application of new measuring techniques using radioactive tracer elements to the problems of plant nutrition has recently renewed interest in the problem of improving the efficiency of fertilizer materials. The technique of adding material as a radioactive isotope provides a means of separating quantitatively the nutrients utilized into two fractions; the native or soil contained fraction and the fertilizer or added material. On the basis of this separation, the amount of nutrient material obtained from the fertilizer can be readily determined.

Two methods of regulating the efficiency of a fertilizer are granulation and placement.

Theoretically, the efficiency of a material like superphosphate should be affected by granulation if it is assumed that only dissolved nutrients are utilized by the plants. Hill (11) has shown that granulation reduces the dissolution rate of superphosphate in water. The reduction of the dissolution rate should cause an increase in uptake if the rate of dissolution is made to more nearly correspond with the rate of phosphorus uptake by the plants. The closer correspondence of the two rates would result in lowered phosphorus concentration in the soil solution at any one time, and this in turn would decrease the fixation of phosphorus by the soil. Hence, it would appear desirable to decrease the dissolution rate of the soluble materials and, as previously stated, this can be accomplished by granulation.

Upon consideration of the effect of placement upon the uptake of phosphorus from a given source, it is noted that by concentrating the material in a band, the material in the center of the band may not come in contact with the soil and thus escapes fixation. Also, the fertilizer may be prevented from dissolution because of the presence of a saturated solution surrounding it. These considerations become important only when the movement of an ion in the soil is very slow, as is the case with phosphorus. Secondly, there is the possibility that with band placement more of the phosphorus is in the root zone when the plants are growing most rapidly. Band placement is especially effective when the plants are young and have small root systems. It has been shown by many investigators that the advantage of localized placement diminishes as the plants age, and may disappear by the time the plants reach maturity.

Collings (5) points out that it is generally accepted that localized placement may promote a heavier growth of roots within the fertilizer zone, but this does not greatly restrict the extension of the root system in all directions outside the fertilizer zone. On the other hand some workers have argued that band or localized placement may reduce the uptake of water or nutrients not contained in the zone of the placement by the concentration of the roots near the fertilizer band.

A greenhouse experiment was designed to test the effect of granulation and placement by measuring the uptake of phosphorus by two important Michigan crops, wheat and field beans. Radiotracer techniques were employed as a more direct approach to the problem with the hope that data of a different sort which would be of some value in the solution of the problem of fertilizer efficiency might be obtained.

REVIEW OF LITERATURE

A. Granulation

Granulation is defined by Hardesty and Clark (10) as the process by which a material is formed into small grains or masses. As applied to fertilizers, the term "granular" is commonly used to describe products which have mean particle sizes greater than are customarily associated with such products and which contain relatively small portions of fine particles. Thus a fertilizer is classed as granular whether the increase in mean size results from cementing together of individual particles, or from mechanical separation of smaller particles from the body of the material.

The practice of granulation has been used for many years for improving the physical condition of fertilizers. Granulation reduces caking and dusting losses, and makes it easier to obtain a more uniform distribution in the field. Large scale commercial production of granulated superphosphate has been carried on for about fifteen years in the United States. It was greatly stimulated by the work of Ross (17) and his associates in the United States Department of Agriculture about thirty years ago. Agronomic experiments testing the effect of granulation on availability of superphosphate in the United States started about 1930.

Sherman and Hardesty (20) have recently prepared a review of experiments conducted with granulated sources of phosphorus during the years 1931-1950. This work reviews 52 experiments conducted in 15 states, Canada and 7 European countries. Their paper was in turn summarized by Starostka (22). The pertinent parts of the latter summary are reported here.

In the 47 experiments in which granulated material was compared with non-granulated under conditions of localized treatments (band placements), about 50 percent of the experiments showed no significant differences due to particle size. About 25 percent of the experiments showed an increase in crop yield due to the use of large granules (10 mesh or over) or briquets. Most of these experiments were on podzolic, lateritic, or low P_2O_5 soils. About 10 percent of the experiments favored a medium sized granule (10-40 mesh). Most of these were on loamy soils. About 15 percent of the experiments, most of which were on sandy loam soils or in pot trials, indicated either a powder or very fine granules (40-150 mesh) to be a superior source. Not all of the results were statistically analyzed.

During the years covered by the summary, 22 experiments were reported which studied the effect of particle size in mixed placement. Of these, 65 percent reported no significant differences in crop yield due to particle size. The remaining 35 percent favored a large particle size. All of these were either in pot experiments or podzolic soils. Not all of the results were statistically analyzed.

Experimental work done in Maryland in 1949 by Borland, et al (2) is similar to the work reported here. In this experiment hairy vetch was grown on Evesboro sandy loam and Cecil clay loam under greenhouse conditions. According to the conclusions from the Maryland experiment there was no significant difference in yield due to granulation. With band placement, there were no significant differences in the percent of plant phosphorus derived from the fertilizer, but with the mixed placement, the percent of phosphorus derived from the fertilizer increased with particle size from 69 percent for regular superphosphate to 92 percent for the granular material of 4-6 mesh.

Several experiments conducted in the Western states in 1950 using a range of particle sizes of calcium meta-phosphate tagged with P^{32} have been reported. Fuller and McGeorge (8) reported little difference in the uptake from calcium metaphosphate as influenced by particle size. The only significant difference at the 5 percent level in the percent phosphorus derived from fertilizer was found in the third cutting of alfalfa and was in favor of -100 mesh over -10 mesh material. This experiment was carried out on a calcareous Laveen clay loam soil.

Schmehl, Olsen and Gardner (19), working on a Las Animas clay soil in Colorado with sugar beets, showed that the absorption of phosphorus increased as the particle size decreased. However, differences were not statistically significant at the 5 percent level for all dates of sampling.

B. Placement

Around 1920 widespread interest developed in the possibility of increasing the efficiency of fertilizer materials by placement which resulted in the organization of the National Joint Committee on Fertilizer Application. This committee has been responsible for the leadership in experimentation on placement and the compilation of experimental results. The ultimate purpose of these summaries is to enable the investigators to make fertilizer application recommendations to the farmers. The suggestions made by this organization are based on experiments conducted by investigators in virtually every section of the United States during the twenty-four year period between 1924 and 1948.

In November 1948, the National Joint Committee on Fertilizer Application made the following recommendations for the two crops involved in this experiment. For field beans, the most effective placement is in a single band approximately one inch to one side and one and one-half inches below seed level. For wheat, it is recommended that the seed and fertilizer be drilled simultaneously with the grain drill. This places the fertilizer close to and in partial contact with the seed. In the trials on wheat, no side-band placement had been investigated. These recommendations are for fertilizers in general and for representative soil and climate conditions.

The above recommendations imply that the net result of these experiments was to favor band placement on these crops.

In 1934 Cook (6) conducted an experiment comparing band application of mixed fertilizers with drill application ahead of planting. Field beans were grown on several important Michigan soils, including Miami loam. The yield results indicated that band application was superior.

Millar (14) and coworkers found that on Brookston clay loam fertilizers placed one-half inch from the seed produced a significantly larger increase in yield of cannery peas than did the same fertilizers broadcast or placed in bands two inches from the seed. The fertilizers were 4-16-8 and 0-16-8 at 300 lbs per acre, and 0-20-0 at 240 lbs per acre.

Frazier (7) working in Maryland with lima beans reported that band placement of 448 lbs of 3-10-8 caused 21 percent more yield than a broadcast application of 800 lbs of 3-10-8. These data were obtained in 1936 on a silt loam soil.

Whittaker (25) has stated, as a conclusion from a fertilizer placement experiment, that the effect of band placement appears to be proportional to the solubility of the salt used. The greater the solubility of the fertilizer source, the more the efficiency is improved by band placement.

Not all of the comparisons of band versus mixed application have resulted in favor of band placement. The summary by Starostka of the Sherman and Hardesty review included the reports from the twenty-three experiments conducted in the period 1931-1950 in which localized and mixed placements were compared. Of these twenty-three experiments, about 50 percent reported no significant difference due to placement. Almost 50 percent of the experiments showed that localized placement gave an increase in yield over mixed placement. Not all of the results were statistically analyzed.

EXPERIMENTAL MATERIALS AND METHODS

A. Soils

The two soils chosen for this experiment were Conover loam and Miami sandy clay loam collected from the R.L. Cook Farm, Ingham County, Michigan by taking the top six inches from several areas selected at random. Although these two soils are very similar in many characteristics they differ in their capacity to retain phosphates against dilute acid extraction.

The Conover series is described by Veatch (24) as dark colored loams and silt loams underlain by yellowish and mottled gray massive gritty clay to depths of several feet. Generally, these soils are non-acid or only slightly acid and are of high fertility. They are found on smooth plains and swales intermediate in drainage between Miami and Brookston types. The original vegetation was hardwood forests; large individual tree growth, mainly of elm, hickory, ash, and basswood. The chief agricultural value of these soils is for the production of hay, grain, beets, alfalfa, and pasture. The larger bodies of these soils constitute first class agricultural lands.

The Miami series is described by Veatch as light brownish loam and silt loam over brownish compact and retentive but granular gritty clay. The clay substratum extends to depths of several feet. These soils are moist but not excessively wet. The surface is usually somewhat acid but the profile is limy at shallow depths and, in general, these soils are considered of relatively high fertility. The land characters where these soils are found are gently rolling upland clay plains, associated swales of wet darker colored clay land, and lakes and muck swamps. Locally, the slopes are steep. The original vegetation was dense forest of sugar maple and beech with variable proportion of oaks and hickory. Agriculturally these soils rank high and are used extensively for general farming purposes.

Several physical and chemical properites of the two soils are tabulated in Table I.

B. Superphosphate

The two superphosphates used in this experiment were radioactive materials supplied by the Unites States Department of Agriculture, Beltsville, Maryland. The specific activity of each material was reported as 0.2 millicuries per gram of P_2O_5. The pile date for each material was February 28, 1951.

The granulated superphosphate was 21.0 percent P_2O_5 by analysis made at the United States Department of Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering laboratory while an analysis performed in the Soil Science laboratory by the author indicated the material to be 20.7 percent P_2O_5. The material was reported by the Beltsville laboratory to be 14-20 mesh.

TABLE I

SOME PHYSICAL AND CHEMICAL PROPERTIES OF THE SOILS USED IN THIS EXPERIMENT

Property	Conover	Miami
Mechanical analysis (hydrometer)		
greater than 50 microns	50.4%	50.9%
5 to 50 microns	29.2%	27.1%
2 to 5 microns	3.4%	4.4%
less than 2 microns	16.8%	17.6%
Organic matter content (C X 1.724)	3.22%	3.05%
Cation exchange capacity	11.70 m.e. per 100 gm	10.10 m.e. per 100 gm
Available P level		
Spurway, reserve method (21)	46 lb/A6in	25 lb/A6in
Bray, total available (4)	87 lb/A6in	93 lb/A6in
pH (by glass electrode)	6.38	5.74
Percent applied P not extractable after incubation		
Spurway, reserve method (21)	84.0	90.0
Bray, total available (4)	75.6	82.1

The non-granulated material was reported to be 19.1 percent P_2O_5 by the United States Department of Agriculture laboratory while an analysis of the material at East Lansing indicated the P_2O_5 content to be 18.4 percent. The particle size distribution of this material was determined with the following results:

8-20 mesh	16%
20-40	21%
40-100	46%
100-200	11%
less than 200	7%

C. Procedure

Greenhouse. In the greenhouse work, field beans and wheat were grown in three-gallon glazed clay pots having an inside diameter of 9.5 inches and a height of 10.75 inches. The pots were placed at random on the greenhouse benches.

The treatments, replicated four times, were as follows:

1. Granulated superphosphate placed in bands one inch below and one inch exterior to the ring of seeds.
2. Non-granulated superphosphate placed the same way.
3. Granulated superphosphate mixed with the top four inches of soil.
4. Non-granulated superphosphate mixed in the top four inches of soil.

Each treatment was at the rate of 1000 pounds per acre as 0-20-0 and was repeated for each of the two soils, Conover and Miami, and each of two crops, Michelite Beans and Henry variety of spring wheat.

Sufficient supplementary nutrients were applied to each pot to simulate per acre applications as follows:

1. 200 lbs of N as $NaNO_3$
2. 500 lbs of K_2O as KCl
3. 5 lbs of borax as H_3BO_3
4. 20 lbs of $CuSO_4$
5. 5 lbs of $ZnSO_4$
6. 20 lbs of $MnSO_4$

These applications, as well as those of superphosphate, were made on an areal basis - the calculated value of 1.13×10^{-5} acre per pot. The supplementary nutrients were added in dry form and mixed with the top four inches of soil in each pot. Moisture content was adjusted regularly by bringing the weight of the pot, soil, and moisture up to field capacity.

Depressions for the planting of the seed and the band application of superphosphate were made by pressing the rim of a clay pot into the moist soil. The ring for the seed was five and one-half inches in diameter and three-quarters of an inch deep. That for the fertilizer was seven and one-half inches in diameter and one and three-quarter inches deep. Care was taken to use only a minimum of pressure to avoid compaction of the adjacent soil.

The seeds were planted on April 11, 1951 and the wheat and beans were thinned to six plants per pot on April 20 and 23 respectively. The above ground plant material from this thinning was retained for analyses for total phosphorus content and radioactive phosphorus. Soil samples were collected from the "mixed placement" pots on April 23.

Harvests were made on May 17, May 29 and June 21 and soil samples were collected from the "mixed placement" pots on approximately the same dates. In each harvest, except the last, one plant was harvested from each pot. In order to have sufficient dry matter for radioactive counting it was necessary to composite the material from the four replicates of each treatment. In the last harvest, the four plants remaining in each pot were harvested for yield data and for chemical analyses. Analyses were made for total and for radioactive phosphorus as with the previous samples.

Laboratory - plant phosphorus. For the determination of phosphorus in the plants which was takeh up from the fertilizer, one gram samples of material were ashed in the muffle furnace which was maintained at 500°C for twelve hours. The ash was dissolved in one and one-half to two milliliters of 2 normal HCl, transferred to a three milliliter volumetric flask and made made up to volume with distilled water. Insoluble silica was retained with the sample. A large eye dropper was used to facilitate the washing and transferring of material.

Aliquots were prepared for counting by transferring one milliliter (33 1/3 percent sample) of the shaken suspension to a weighed aluminum disk nine centimeters in diameter. A drop of deliquescent salt solution (20 percent $CaCl_2$) was added to each disk and allowed to dry in open air. The $CaCl_2$ was added to prevent dusting of the sample. In order to facilitate calculating the area of residue, a thin coating of stop-cock grease was placed around the border of the disk to keep the liquid in a more circular pattern.

When the disks were dry, radiation was measured with a Tracerlab Auto Scaler - Mark II using a Tracerlab tube TGC-2/1B84 with a mica window; absorption thickness of 1.9 mg/cm^2. To assure uniform geometry for different samples, two concentric depressions were turned into a lucite block. The deeper one was made to fit the aluminum disk containing the sample whereas the second was cut to fit the tube shield. With this arrangement the tube could be centered over the sample with a distance of about three millimeters between the sample and the mica window. This procedure was suitable for counting of plant ash samples up to about eight half lives with reasonable precision. At least five series of 256 counts each were made for each sample. Correction for mass absorption was made on each average count. The counts from a given sample were compared to those from a known standard for the calculation of concentration. The standard was counted at the beginning and end of each period of counting which was usually about four hours. The counts were made following the directions outlined in the Auto Scaler Manual (9).

For the radiation measurements on materials collected on the fourth sample, it was found that the precision of counting could be improved by use of a different procedure. Trials revealed that by compressing the ground air-dry plant material into small pellets, larger samples could be effectively concentrated into the defined counting volume and thereby increase the counts per minute which could be obtained from a given sample. This method also proved much simpler, more rapid, and more accurate by reducing the number of steps in the procedure.

The procedure used was an adaptation of the method developed by Dion and described by MacKenzie (12). However, with the use of the Gieger-Mueller tube with a very thin mica window (TGC-2), it was found that sufficient area to get a satisfactory counting rate could be exposed to the tube by pressing the material into a pellet instead of hollow cylinder (as developed by Dion). The diameter of this pellet was made equal to that of the mica window.

The pellets were pressed in a specially designed and constructed form using a Carver press. Several pressure and time combinations were tried and the combination of 12,000 lbs per square inch for one minute (least rigorous tried) was found to be as effective as any tested.

The pellets were one inch in diameter and five-sixteenths of an inch thick, containing six grams of air-dry plant material. The weight and thickness of the pellet is not critical if the absorption thickness is sufficient to completely absorb the beta radiation emitted by atoms furthest from the tube. Standards for this analysis were prepared by mixing an aliquot of standard P^{32} solution with a portion of check material. The counting was carried out in the manner described above.

<u>Laboratory procedure for total phosphorus</u>. The portions of samples remaining after the aliquot for counting was removed (2 milliliters) were filtered to remove the solid silicon dioxide and diluted for the determination of total phosphorus. A number of aliquots were dehydrated to remove soluble silica and it was found that this procedure has no effect on the accuracy of the determination. This is in agreement with the findings of Truog and Meyer (23) even though a different reducing agent was employed for the Deniges' blue reaction.

The total phosphate was determined colorimetrically by the Deniges' blue reaction. The procedure followed was as outlined by Bray (4) using the Fiske-Subbarow reducing agent which is a mixture of sodium sulfite, sodium bisulfite, and amino-naphthol-sulfonic acid . The color was allowed to develop for fifteen minutes and then its intensity was measured with an Evelyn Colorimeter using a 620 millimicron filter. Standards for comparison were prepared from mono-potassium phosphate.

<u>Laboratory methods for soil characterization.</u> The most important soil characteristics in this experiment were the available phosphate levels at the different sampling dates and the phosphate fixing capacities. The available phosphate levels were determined by two rapid test methods. These two differed only in the method of extraction used.

One procedure was that of Spurway for the "reserve" soil phosphorus in which phosphorus is extracted with 0.135 normal HCl. Two gram samples of soil were shaken with eight milliliters of the extracting solution for one minute, filtered and diluted 5:1. Extracted phosphorus was measured colorimetrically with the Evelyn Colorimeter.

The second method of extraction used was that of Bray (4) for removal of "total available" soil phosphorus. Two gram samples of soil were shaken with twenty milliliters of a solution of 0.1 normal with respect to HCl and 0.03 normal in NH_4F, filtered, and diluted 12.5:1 for colorimetric determination.

The phosphate fixing capacities of the two soils were measured by adding several different increments of phosphate as mono-potassium phosphate to soil samples in tumblers in the laboratory and incubating for several weeks, then extracting with the methods described above. The phosphate was added in amounts calculated to simulate application of 60, 120, 300, 600 and 1200 lbs per acre of phosphorus in duplicate for each soil. The cultures were incubated for six weeks under laboratory conditions. During this period, the soil was moistened to 35 percent water and allowed to dry to 7 percent three times.

The mechanical analysis of each soil was made using the hydrometer method as described by Bouyoucos (3).

Organic matter content was determined using the carbon train method with ascarite (sodium hydroxide asbestos) as the CO_2 absorbent.

The cation exchange capacity was measured according to the method of Peech (16). Normal neutral ammonium acetate was used to saturate the complex with ammonium ions, which were then replaced with 10 percent sodium chloride solution and determined by the Kjeldahl method.

Soil reaction values were determined with the glass electrode and the Beckman pH meter, model H-2, using 1:1 soil-water suspensions. The soil-water mixtures were allowed to stand for fifteen minutes before readings were made.

All of the above mentioned soil properties were determined on duplicate samples with a third determination made when needed.

Laboratory method for superphosphate analysis. The superphosphate used was analyzed for total phosphorus in its original condition and after it had been in band placement in the soil for the period of plant growth. The material recovered from band placement was carefully removed from the soil with tweezers and sorted under a hand lens to remove soil particles. A reasonably pure sample of the residue was obtained in this manner. Phosphorus in this recovered material and in the original fertilizer was determined using the standard A.O.A.C. method (volumetric option) (1) for fertilizer phosphorus. Briefly, this method consists of digestion of the samples in HNO_3 and HCl, filtration, dilution, and precipitation of phosphorus as ammonium phospho-molybdate. The precipitate is dissolved in standard NaOH and the excess NaOH titrated with standard HCl using phenolphthalein as an indicator.

The particle size distribution of the non-granulated superphosphate was determined by shaking at one-quarter speed a 50 gram sample in an appropriate nest of sieves fitted to the Cenco-Meinzer sieve shaker (catalog number 18480) for fifteen minutes. The residue on each sieve was brushed into a weighing can and weighed.

RESULTS AND DISCUSSION

A. Soil phosphorus

Original phosphorus level. As shown in Table I, the Conover soil contained 46 lbs of phosphorus extractable with 0.135 normal HCl, while the Miami soil contained 25 lbs per acre six inches.

Spurway and Lawton (21) have reported the critical level with this test to be about 40 lbs per acre. Soil containing less than this amount of acid extractable phosphorus can be expected to respond to phosphate fertilization, while those containing more usually do not. Using this hypothesis, only small yield response of crops to phosphate on these soils would be expected with a greater plant response on the Miami than on the Conover soil. It was found in this experiment that there was more response on the Miami soil as shown by the yield data in Tables VII, VIII, IX and X.

Bray (4) has developed a system for predicting the response to fertilizers. According to this system, the soil nutrients have a variable availability which depends on the mobility of the nutrients in the soil and on the nature of the plant. Those with little mobility such as phosphorus, tend to follow the Baule percentage yield relationship.

The soils used in this experiment were found to contain 87 lbs per acre six inches of total available phosphorus for the Conover and 93 lbs for the Miami according to the method of Bray. These values are both high according to Bray's criteria and consequently very little if any response to fertilization would be expected. From the yield data it may be noted that there was no appreciable increase in yield.

Fixation studies. Since the laboratory extraction procedures used to determine the levels of available phosphorus in the soils have been found to have good correlation with yield and response measurements, these procedures could also be used to measure the capacity of soils to fix phosphorus in unavailable form.

A great many phosphate fixation studies have been carried out by investigators, and from their reports, it would appear that the process of phosphorus fixation is probably a combination of chemical precipitation reactions, replacement reactions, and physical and chemical sorption. It seems, that if fixation is effectively such a combination, the capacity of a given soil to "fix" phosphorus should be definite, and that it should be possible to saturate each of the capacities individually and therefore possible to saturate the total capacity. The large quantities of phosphorus (up to 2830 lbs P_2O_5 per acre) used in the fixation trials in this experiment were used in an attempt to saturate the capacities of the two soils used.

The criterion used to determine saturation was that the percentage of the applied phosphorus not extractable should decrease when the saturation level was attained. Several application rates were used. The data for these trials are given in Tables II, III, IV, and V.

TABLE II

PHOSPHORUS FIXATION BY CONOVER SOIL AS MEASURED BY THE SPURWAY RESERVE EXTRACTION METHOD*

Phosphorus applied - lbs/acre/6"	Extractable P -lbs/acre/6"	Applied P recovered -lbs/acre/6"	Applied P not recovered - %
0	40		
61	48	9	85.2
123	59	19	84.6
131	56	16	87.8
309	86	46	85.1
317	81	41	87.1
626	155	115	81.7
632	150	110	82.6
1228	271	231	87.6
1239	280	240	83.4
		average	84.0

*All values expressed as elemental phosphorus (P).

TABLE III

PHOSPHORUS FIXATION BY CONOVER SOIL AS MEASURED BY THE BRAY TOTAL AVAILABLE EXTRACTION METHOD*

Phosphorus applied - lbs/acre/6"	Extractable P -lbs/acre/6"	Applied P recovered -lbs/acre/6"	Applied P not recovered - %
0	88		
61	103	15	73.8
123	120	32	74.0
131	118	30	77.1
309	163	75	75.7
317	163	75	76.4
626	248	160	74.4
632	253	165	73.9
1228	368	280	78.4
1239	380	292	76.2
		average	75.6

*All values expressed as elemental phosphorus (P).

TABLE IV

PHOSPHORUS FIXATION BY MIAMI SOIL AS MEASURED BY THE SPURWAY RESERVE EXTRACTION METHOD*

Phosphorus applied - lbs/acre/6"	Extractable P -lbs/acre/6"	Applied P recovered -lbs/acre/6"	Applied P not recovered - %
0	21		
61	26	5	92.1
127	29	8	94.3
128	33	12	91.6
305	51	30	90.9
308	48	27	91.2
628	84	63	90.7
635	87	66	90.1
1230	177	156	88.5
1244	186	165	87.9
		average	90.0

*All values expressed as elemental phosphorus (P).

TABLE V

PHOSPHORUS FIXATION BY MIAMI SOIL AS MEASURED BY THE BRAY TOTAL AVAILABLE EXTRACTION METHOD*

Phosphorus applied - lbs/acre/6"	Extractable P -lbs/acre/6"	Applied P recovered -lbs/acre/6"	Applied P not recovered - %
0	95		
61	107	12	81.7
127	117	22	83.9
128	122	27	79.5
305	150	55	82.1
308	145	50	84.3
628	200	105	83.8
635	208	113	82.4
1230	327	232	81.2
1244	344	249	80.7
		average	82.1

*All values expressed as elemental phosphorus (P).

Inspection of the data in Tables II, III, IV, and V shows that the percentage of applied phosphorus not recoverable remained essentially constant over the range investigated. Variations which did occur are probably within experimental error. Thus, it can be assumed that either some factor not considered above enters into the fixation capacity of a soil, or the total phosphorus retention capacity was not saturated even at the highest level of application of some seven and one-half tons of superphosphate per acre six inches.

Effect of crop growth on available phosphorus level. Soil samples were collected at the different sampling dates and analyzed for available phosphorus by both methods. Data from these analyses show that the change in available phosphorus during the growing period was small. The available phosphorus levels for each condition on each date are given in Table VI. It should be noted that in some cases a decrease did occur and that in some cases the reduction amounted to about 10 percent in the "Spurway extractable", and often somewhat more in the "Bray total available". The fact that the amounts of extractable phosphorus is higher for non-granulated treatment than for granulated treatment probably is related to the differences in dissolution rates of the two materials. This difference had virtually disappeared by the second sampling date and consequently, an indication of the effective life of the granules or the length of time during which particle size has an effect on dissolution rate of the material is given.

TABLE VI

EFFECT OF CROP GROWTH ON AVAILABLE PHOSPHORUS IN THE SOIL

Condition	Pounds of available phosphorus per acre six inches							
	Spurway Reserve Extraction				Bray Total Available			
	April 23	May 18	May 29	June 21	April 23	May 17	May 29	June 21
Conover Loam								
Wheat								
check	48	52	42	44	71	88	96	92
gran. mixed	106	102	104	97	189	162	179	161
non-gran. mixed	110	97	92	97	225	150	160	172
Beans								
check	48	48	45	42	90	94	81	74
gran. mixed	97	92	90	92	179	167	161	147
non-gran. mixed	106	94	96	89	206	170	170	150
Miami Sandy Clay Loam								
Wheat								
check	23	23	23	18	87	74	70	71
gran. mixed	37	39	38	42	120	107	120	118
non-gran. mixed	---	41	34	47	---	106	117	123
Beans								
check	24	34	26	17	96	70	70	70
gran. mixed	46	37	38	33	123	124	120	108
non-gran. mixed	44	49	44	39	110	117	147	113

Crop growth during the 24 days from April 23rd to May 17th could scarcely account for the large decreases in available phosphorus noted in some cases. Hence, the difference must be due to a change of state; that is, from a soluble salt at the first date to a reverted or "fixed" form on the second date.

B. Yield

Yield measurements were made on the material collected on the fourth sampling date when the plants were 71 days old. At this time the fruit of both the beans and the wheat was well developed but not sufficiently ripe to allow threshing. For this reason, fruit weights include the entire fruiting body in each case. The fruiting bodies were separated from the foliage when the material was first harvested to avoid shattering losses. Yield measurements are reported as follows:

1. Total weight per plant.
2. Number of fruits per plant.
3. Weight of fruit per plant.
4. Weight of foliage per plant.

The data are recorded in Tables VII, VIII, IX, and X. The values given represent the average for sixteen plants from four pots in each case.

The data reveal that the treatments had a greater effect on the yields of plant material from Miami than from Conover soil but, as was expected, in neither case was the increase very large.

TABLE VII

YIELD OF FIELD BEANS ON CONOVER SOIL

Treatment	wt./ plant grams	fruits/ plant number	fruit/ plant grams	foliage/ plant grams
check	8.70	5.50	4.15	4.55
gran. band	8.64	5.75	4.03	4.61
gran. mixed	8.79	5.56	4.05	4.74
non-gran. band	8.40	5.19	3.83	4.57
non-gran. mixed	9.06	5.50	4.05	5.01

no significant difference at 5% level

TABLE VIII

YIELD OF FIELD BEANS ON MIAMI SOIL

Treatment	wt./ plant grams	fruits/ plant number	fruit/ plant grams	foliage/ plant grams
check	8.14	5.50	4.51	3.53
gran. band	8.39	6.94	5.46	3.83
gran. mixed	9.27	6.50	4.33	4.94
non-gran. band	8.40	6.13	4.26	4.14
non-gran. mixed	9.34	6.56	4.84	4.50

no significant difference at 5% level

TABLE IX

YIELD OF SPRING WHEAT ON CONOVER SOIL

Treatment	wt./ plant grams	fruits/ plant number	fruit/ plant grams	foliage/ plant grams
check	5.58	3.50	2.58	3.00
gran. band	6.36	3.69	2.74	3.62
gran. mixed	6.01	3.86	2.74	3.27
non-gran. band	5.36	3.52	2.57	2.79
non-gran. mixed	6.24	3.87	3.01	3.23

no significant difference at 5% level

TABLE X

YIELD OF SPRING WHEAT ON MIAMI SOIL

Treatment	wt./ plant grams	fruits/ plant number	fruit/ plant grams	foliage/ plant grams
check	4.39	3.38	2.26	2.13
gran. band	6.30	4.31	2.80	3.50
gran. mixed	6.42	4.38	3.05	3.37
non-gran. band	5.80	4.02	3.00	2.80
non-gran. mixed	6.51	5.27	3.02	3.49

no significant difference at 5% level

Statistical analysis of the yield data failed to reveal any significant differences between treatments because of the great variability within a single treatment. Certain trends can be pointed out in the yield data. It is noted that the values cited are usually higher for mixed placement than for band placement. This is true except in the case of spring wheat on Miami soil. In the comparison of granulated and non-granulated material, the yield differences are inconsistent, consequently very little can be deduced from the data. From a summary of all yield comparisons it would appear that the non-granulated material may have been slightly superior on both soils for both crops.

Attempts were made to measure the early effects of the treatments by making height measurements of the plants at the ages of thirty-six and forty-eight days. Again the great variation between individuals became a problem but by discarding the individuals with extreme deviations from the mean in each pot, average heights were obtained which could be considered reliable indicators. These averages are given in Table XI, and it is noted that the differences due to treatment were small. They were of about the same order of magnitude as the differences in final yields.

During the growing season some general observations were recorded. There were no marked differences in the vigor of the plants, nor in the rate of growth. Blossoms appeared on all plants at about the same time. Most wheat plants were

TABLE XI

INFLUENCE OF TREATMENT ON THE HEIGHT OF PLANTS

Treatment	Average height per plant - inches	
	Age - 36 days (average of 18 plants)	Age - 48 days (average of 14 plants)
Conover Loam		
Wheat		
check	14.1*	22**
gran. band	14.7	26
gran. mixed	14.9	26
non-gran. band	14.9	25
non-gran. mixed	14.8	26
Beans		
check	7.7*	25**
gran. band	9.7	22
gran. mixed	9.7	23
non-gran. band	9.3	22
non-gran. mixed	8.7	24
Miami Sandy Clay Loam		
Wheat		
check	14.1	25**
gran. band	14.5	24
gran. mixed	14.5	25
non-gran. band	15.2	27
non-gran. mixed	14.6	26
Beans		
check	6.8	20**
gran. band	8.5	24
gran. mixed	7.7	22
non-gran. band	9.3	22
non-gran. mixed	7.8	22

* average of 10 plants
** average of 8 plants

jointing at or about the age of 36 days, and the beans had an average of seven leaves per plant regardless of treatment. At the age of forty days, heads were appearing on the wheat plants, but the order of appearance of heads was apparently not related to treatment. Blossoms appeared on many of the bean plants at the age of forty days but again the appearance of blossoms seemingly was unrelated to treatment.

C. Phosphorus content of plant material

Total phosphorus content. The values for total phosphorus content appear in Table XII for wheat and in Table XIII for beans. In spite of the high phosphorus level on which the test crops were grown, the total phosphorus contents were not much higher in the mature plants than those reported as average values for these crops by Morrison (15). These data were analyzed statistically by the analysis of variance method and it was found there was no significant difference at the five percent level although certain trends are indicated. For the last sampling date, as in the total yield data, mixed placement resulted in slightly higher phosphorus content than band placement for both crops and both soils. There appears to be no consistent effect of granulation in the last date of sampling.

In the data for the third sampling date, band placement appears superior for the wheat on both soils. However, the beans grown with mixed placement are slightly higher in phosphorus content. Granulated phosphorus resulted in a higher total phosphorus content in the wheat grown on Conover soil,

TABLE XII

CONCENTRATION OF PHOSPHORUS IN DRY WHEAT MATERIAL

Soil	Conover				Miami			
Fertilizer	Gran.		Non-gran.		Gran.		Non-gran.	
Placement	band	mix	band	mix	band	mix	band	mix
	milligrams per gram *				milligrams per gram *			
April 23	5.40	7.56	4.74	6.45	6.15	4.35	5.25	3.92
May 17	3.60	3.90	4.35	4.35	4.07	3.90	3.68	4.05
May 29	3.55	2.70	2.70	2.48	3.00	2.17	3.37	2.85
June 21	2.99	3.34	3.88	3.38	3.43	2.61	2.84	3.12

* to convert to percent phosphorus, divide by 10

no significant difference at 5 percent level by analysis of variance

TABLE XIII

CONCENTRATION OF PHOSPHORUS IN DRY BEAN MATERIAL

Soil	Conover				Miami			
Fertilizer	Gran.		Non-gran.		Gran.		Non-gran.	
Placement	band	mix	band	mix	band	mix	band	mix
	milligrams per gran *				milligrams per gram *			
April 23	5.02	4.71	5.81	5.37	7.38	5.22	5.28	5.94
May 17	2.94	2.25	3.60	2.29	2.70	2.48	4.57	2.57
May 29	2.40	2.70	2.50	2.72	2.48	2.40	2.48	2.62
June 21	3.88	3.98	3.90	4.06	3.85	4.12	3.82	3.85

* to convert to percent phosphorus, divide by 10

no significant difference at 5 percent level by analysis of variance while non-granulated superphosphate resulted in a higher phosphorus content in the wheat grown on Miami soil. The effect of granulation was inconsistent for the bean plants of the third sampling date.

An inspection of the data in Table XII, for the second sampling date, reveals that for wheat grown on Conover soil the non-granulated superphosphate gave a somewhat higher phosphorus content, while for wheat grown on Miami the granulated fertilizer gave slightly higher values. The effect of placement was inconsistent.

According to the data in Table XIII for the second sampling date, phosphorus content of beans, at the age of thirty-six days, was appreciably higher in those grown with band placement on both soils. It also appears that the uptake of phosphorus from non-granulated superphosphate was greater where the band placement was used.

On the first sampling date, mixed placement resulted in higher phosphorus content for the wheat grown on Conover, lower phosphorus for the wheat grown on Miami, and lower phosphorus content for the beans grown on either soil. The effect of granulation was somewhat inconsistent on the first sampling date, as shown in Table XII, but granulated material increased the uptake of phosphorus by wheat, reduced uptake by beans on Conover soil and increased the uptake by beans on Miami soil.

For all combinations of soil, crop, and treatment the total phosphorus content was high in the young plants, decreased to a minimum at the third sampling, and then increased again but never attained the high level found in the young plants.

<u>Phosphorus from fertilizer</u>. The content of fertilizer phosphorus in the plants was determined as described in the procedure by measuring the radiation due to the radioisotope content. The values obtained by this measurement are given in Table XIV for wheat, and in Table XV for beans. It may be seen from the tables and also from Figures 1 to 4 that the content of fertilizer phosphorus in the tissue was low at the first sampling, increased to a maximum by the time of the second sampling, and then gradually and almost linearly diminished. This trend was true regardless of the soil, crop or treatment and is entirely as would be expected. The first sampling was made when the plants were only eleven days old. At this time, probably an appreciable portion of the phosphorus in the tissue came from the reserve in the seed from which the plants grew. As the plants grew older, more of their phosphorus came from the fertilizer until such time as the root system extended beyond the zone of influence of the fertilizer phosphorus. This condition should be expected to occur earlier with the band than with the mixed placement, but this difference did not show up in this experiment. Probably samplings were not made with sufficient frequency to find such a relationship.

It will be noted that the increase in fertilizer phosphorus from the first to the second sampling was always greater

TABLE XVI

CONCENTRATION OF FERTILIZER PHOSPHORUS IN DRY WHEAT MATERIAL

Soil	Conover				Miami			
Fertilizer	Gran.		Non-gran.		Gran.		Non-gran.	
Placement	band	mix	band	mix	band	mix	band	mix
	milligrams per gram *				milligrams per gram *			
April 23	1.21	1.87	0.73	1.96	1.53	1.15	1.33	0.95
May 17	3.26	3.01	4.34	3.20	4.03	3.24	3.53	2.99
May 29	2.86	1.84	2.61	2.29	2.68	1.78	3.10	2.03
June 21	1.92	1.70	2.22	1.62	2.24	1.36	1.81	1.40

* to convert to percent, divide by 10

TABLE XVII

CONCENTRATION OF FERTILIZER PHOSPHORUS IN DRY BEAN MATERIAL

Soil	Conover				Miami			
Fertilizer	Gran.		Non-gran.		Gran.		Non-gran.	
Placement	band	mix	band	mix	band	mix	band	mix
	milligrams per gram *				milligrams per gram *			
April 23	0.78	0.70	1.06	0.60	0.93	0.51	1.29	0.48
May 17	2.83	1.85	3.10	1.91	2.76	1.28	2.81	1.59
May 29	2.52	1.73	2.15	1.87	2.26	1.57	2.25	1.61
June 21	1.68	1.38	1.45	1.56	1.61	1.35	1.01	1.24

* to convert to percent, divide by 10

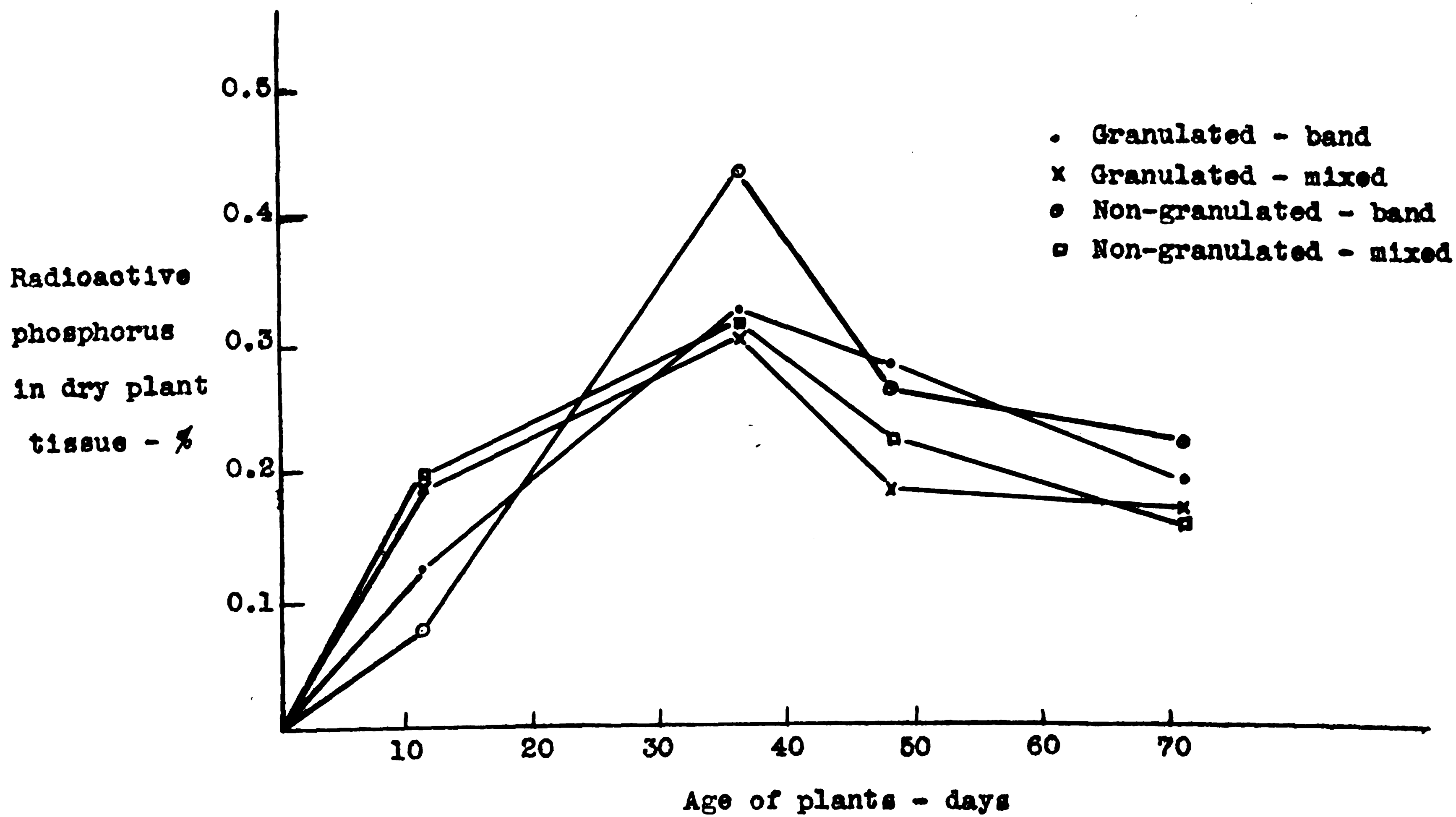

Fig. 1 The effect of plant age on concentration of fertilizer phosphorus in wheat grown on Conover soil.

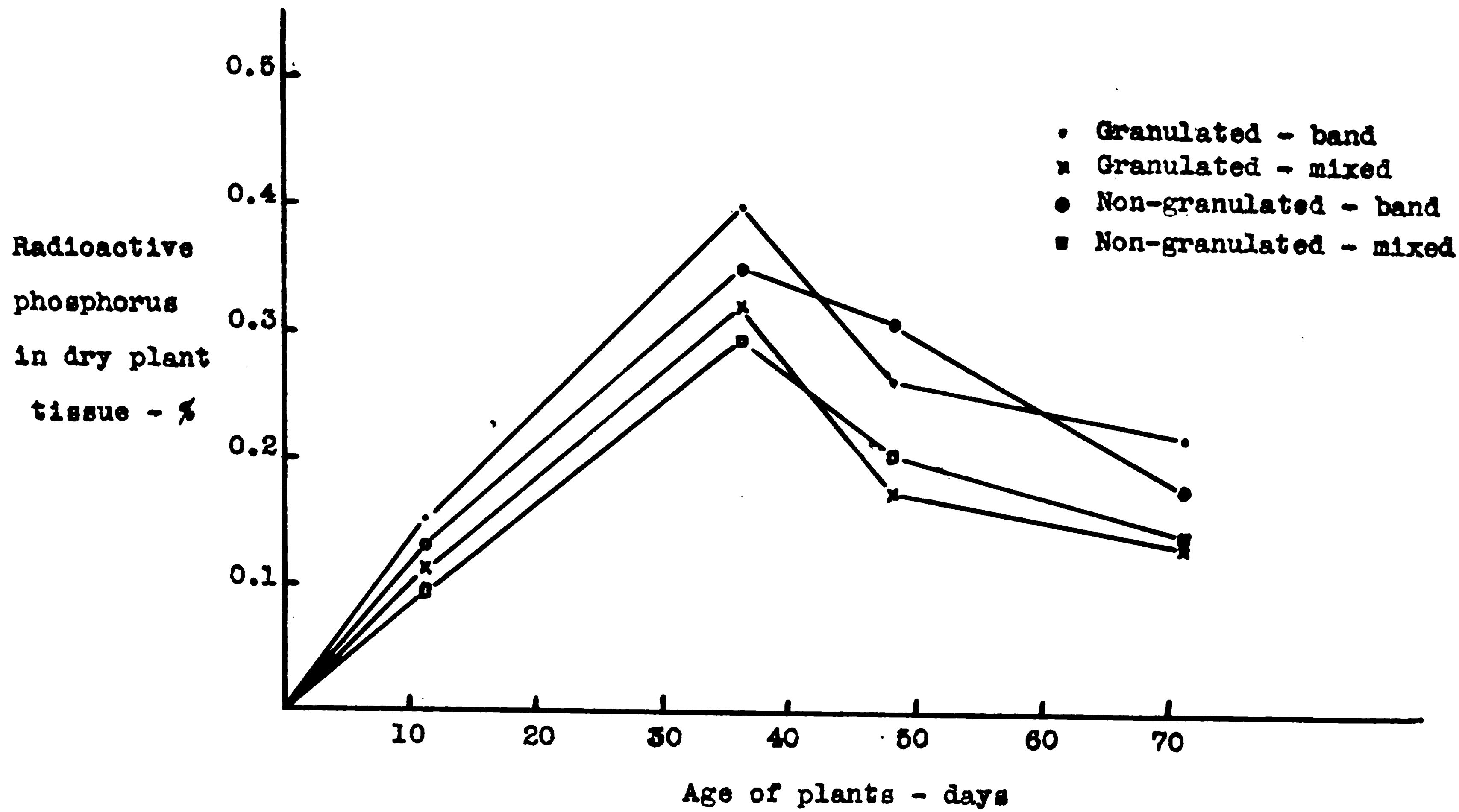

Fig. 2 The effect of plant age on concentration of fertilizer phosphorus in wheat grown on Miami soil.

Fig. 3 The effect of plant age on concentration of fertilizer phosphorus in beans grown on Conover soil.

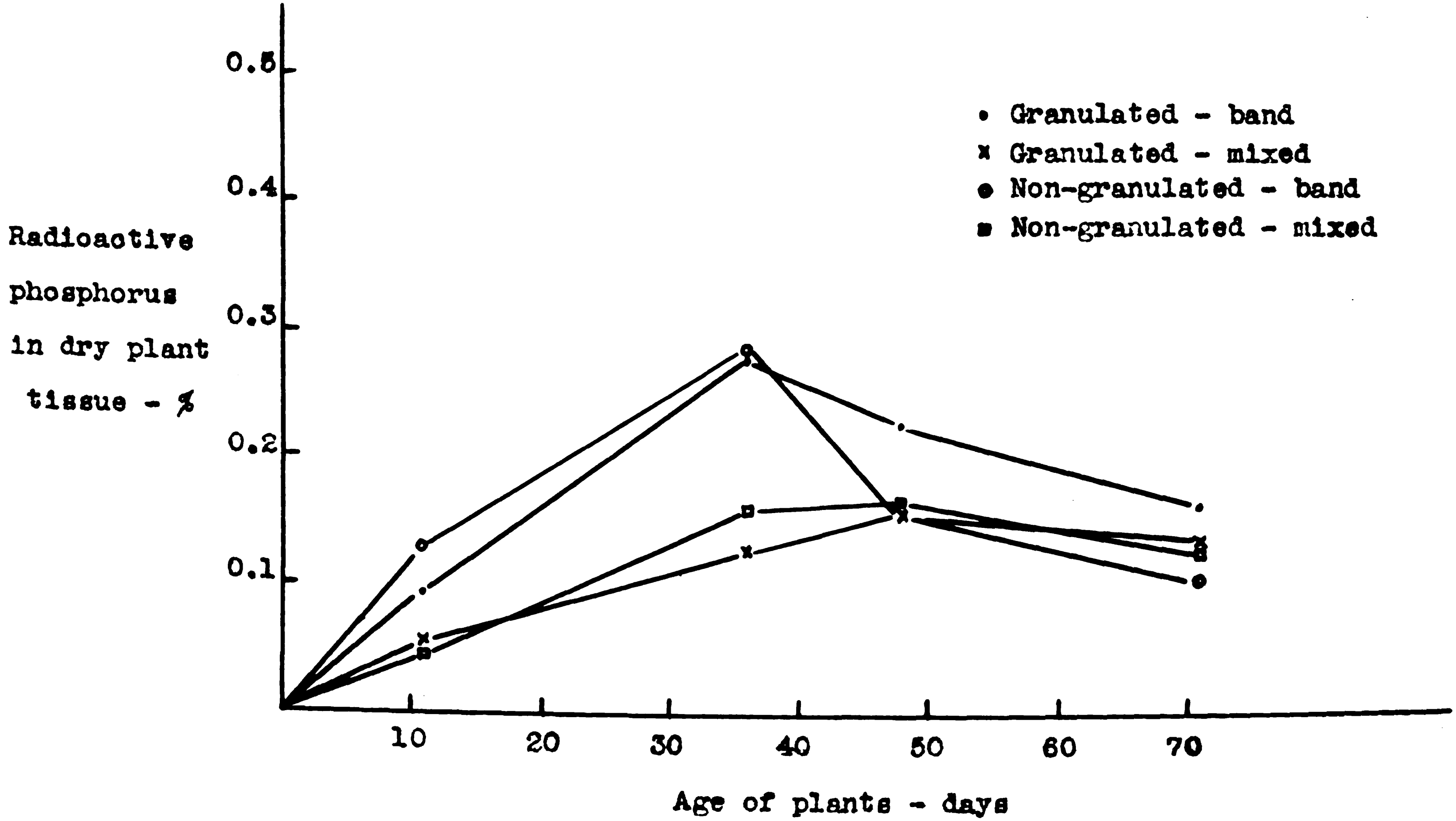

Fig. 4 The effect of plant age on concentration of fertilizer phosphorus in beans grown on Miami soil.

for the band placement than for the mixed placement. This was especially true in the case of wheat. This fact suggests that a fully effective root system had not developed to include the fertilizer band (one inch below and one inch to the side) within twelve days.

The concentration of fertilizer phosphorus was generally somewhat higher in the mature wheat than in the mature beans, although this trend did not follow for total phosphorus. This was probably due to the difference in the root systems of the two crops. The beans foraged more effectively in the soil below the fertilizer level (fertilizer phosphorus never applied to depth greater than four inches). However, the decrease in radioactive phosphorus content in both crops after the second date, regardless of placement, would indicate that both crops undoubtedly derived considerable phosphorus outside of the zone of fertilizer influence.

The effect of placement on the concentration of fertilizer phosphorus in the plants may be noted from Tables XIV and XV. It is readily seen that the band placement was superior in all except the first sampling date in the case of wheat grown on Conover soil. Here, for some reason, mixed placement produced greater plant absorption of phosphorus. The effect of placement did, however, show some variation with time, being greatest at the second sampling. This tendency is graphically illustrated in Figures 1 to 4.

Figures 1 to 4 also illustrate the effect of granulation on the concentration of fertilizer phosphorus in the plant material. The effect of granulation is inconsistent and although no analysis of variance was made of these data, there probably was no significant difference due to granulation. From the conclusions made in the section on soil phosphorus studies, such a result would be expected and certainly no differences due to granulation would be evident after the first sampling date.

Fraction on plant phosphorus derived from fertilizer. Among the experiments in recent years using radioactive phosphorus for evaluating a fertilizer source or practice, the most commonly used basis has been the percent of total plant phosphorus derived from the fertilizer. This criterion is also included in this experiment although it is believed that the basis discussed in the last section (page 36) is more suitable for measuring the efficiency of the treatments, separately and in combination.

The percent plant phosphorus derived from the superphosphate is given in Table XVI for wheat and in Table XVII for beans. The values presented were calculated from the data in Tables XII, XIII, XIV and XV. These data are graphically depicted in Figures 5 to 8.

The data indicate that band placement resulted in a larger percentage of fertilizer phosphorus in the plant in all cases except at the first sampling of wheat. Here the mixed placement produced the higher efficiency. It is interesting to note that in the first sampling the percentage fertilizer phosphorus

TABLE XVI

PERCENT PHOSPHORUS IN WHEAT DERIVED FROM FERTILIZER

Soil	Conover				Miami			
Fertilizer	Gran.		Non-gran.		Gran.		Non-gran.	
Placement	band	mix	band	mix	band	mix	band	mix
April 23	22.7	24.7	15.4	30.4	24.9	26.4	25.4	26.1
May 17	90.6	77.2	99.6	73.7	98.8	83.4	96.1	73.9
May 29	80.6	63.3	96.7	84.0	89.4	82.1	92.1	73.1
June 21	64.2	51.0	57.2	48.0	65.4	52.2	61.8	45.0

TABLE XVII

PERCENT PHOSPHORUS IN BEANS DERIVED FROM FERTILIZER

Soil	Conover				Miami			
Fertilizer	Gran.		Non-gran.		Gran.		Non-gran.	
Placement	band	mix	band	mix	band	mix	band	mix
April 23	15.5	14.8	18.3	11.2	12.8	9.8	24.4	8.1
May 17	96.4	82.3	86.2	83.4	100	51.7	61.5	66.6
May 29	100	62.3	86.1	69.3	91.2	65.5	90.9	61.4
June 21	43.4	34.6	37.2	38.6	42.0	32.8	26.6	32.2

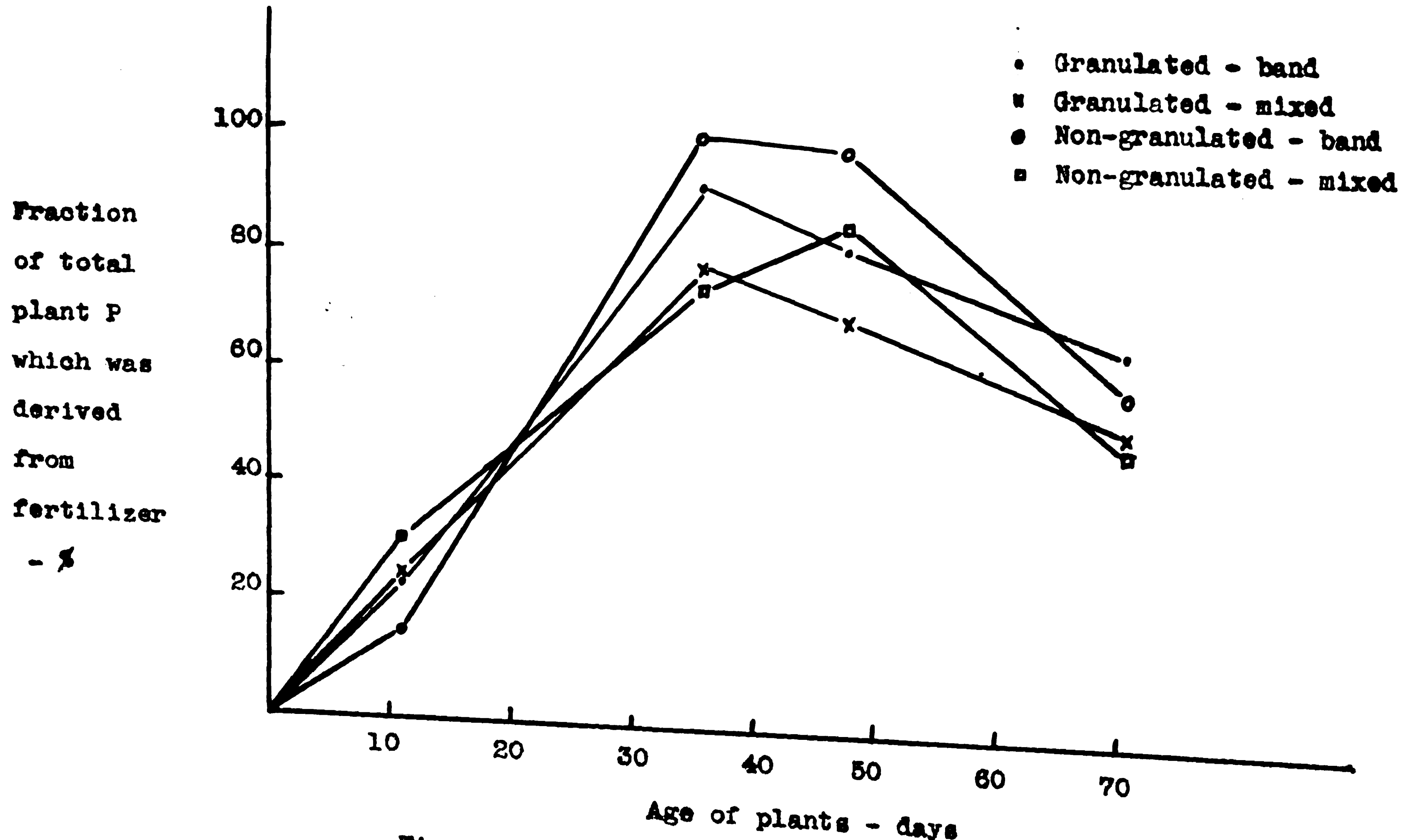

Fig. 5 Composition of plant phosphorus with respect to source for wheat grown on Conover soil.

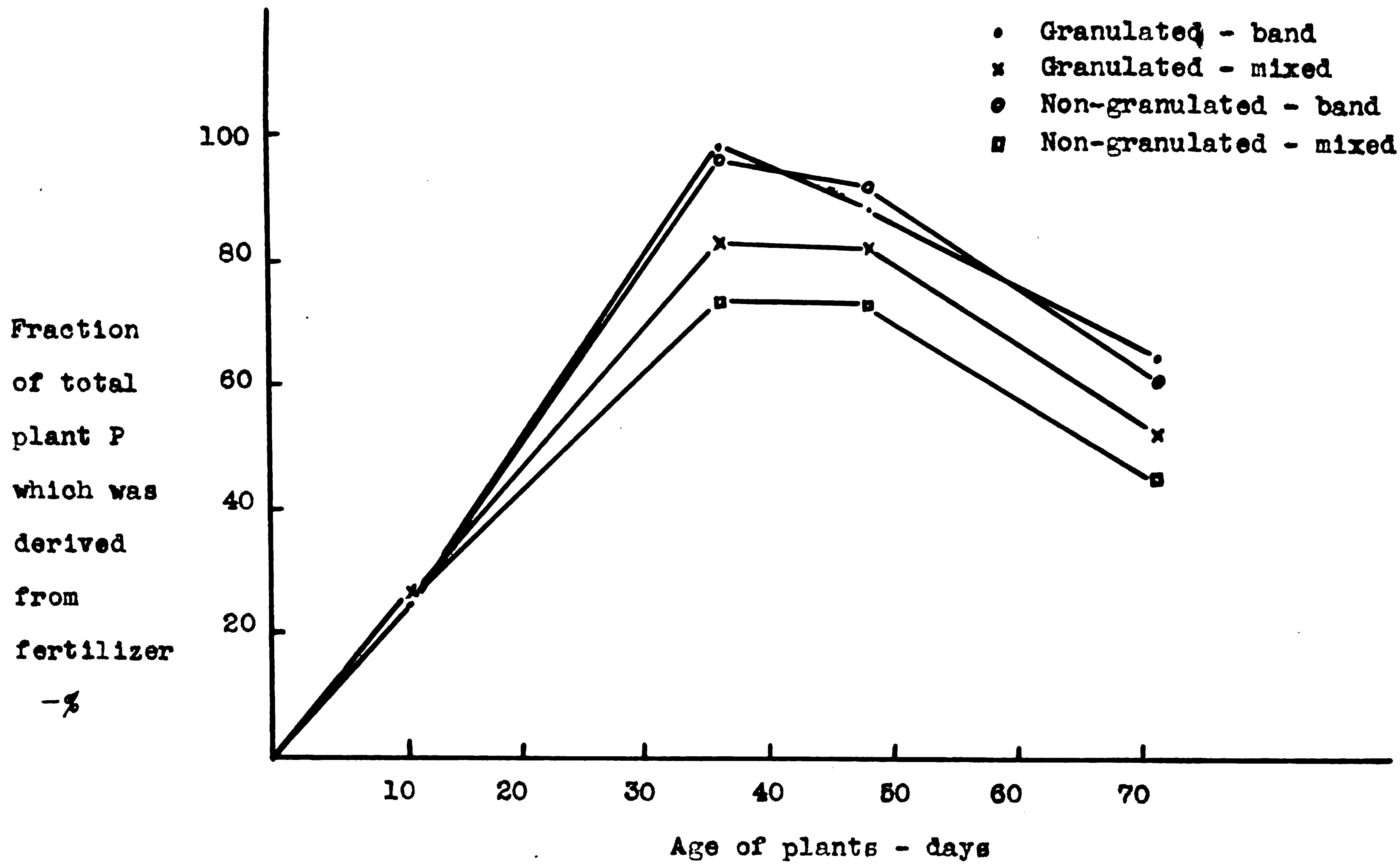

Fig. 6 Composition of plant phosphorus with respect to source for wheat grown on Miami soil.

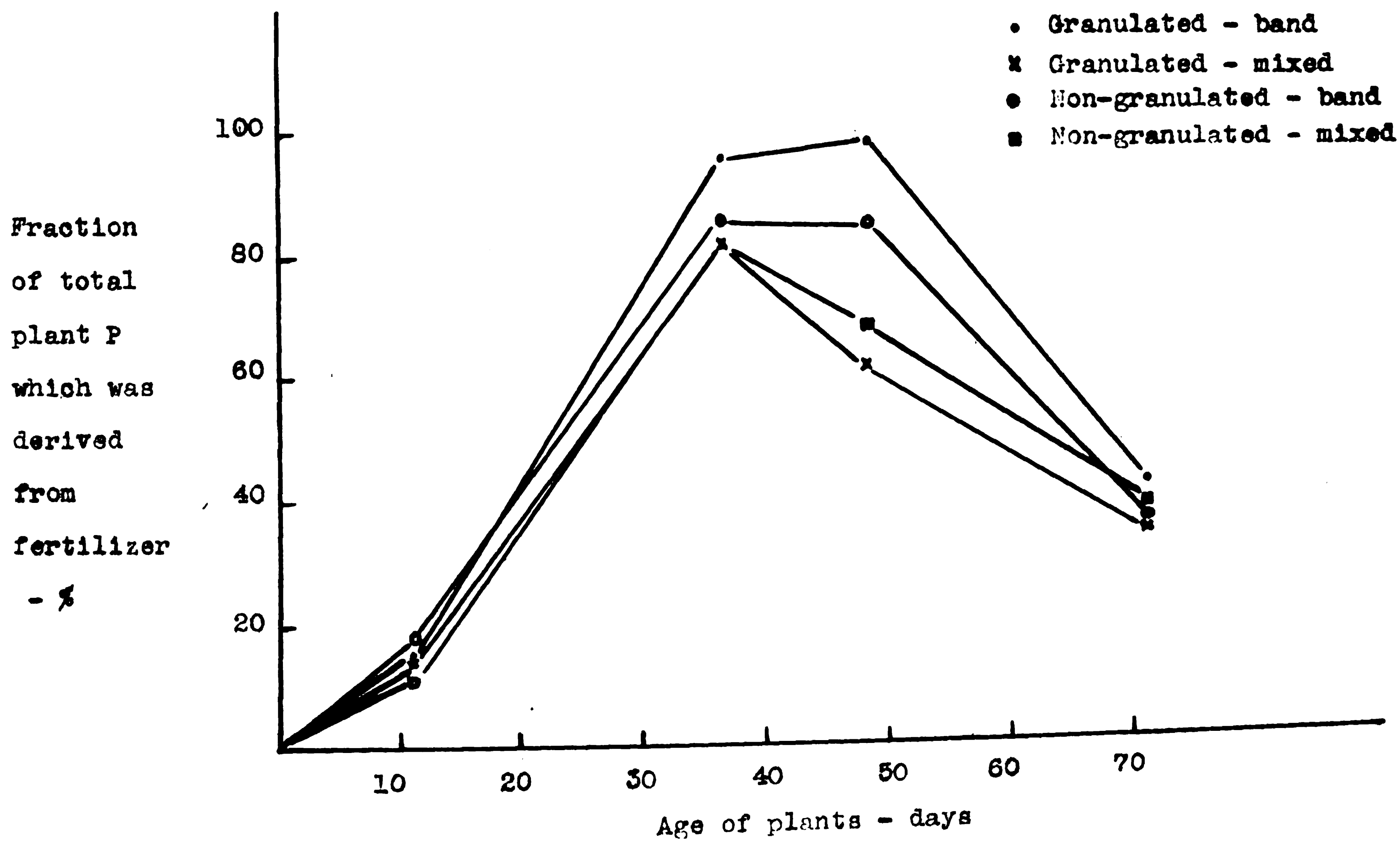

Fig. 7 Composition of plant phosphorus with respect to source for beans grown on Conover soil.

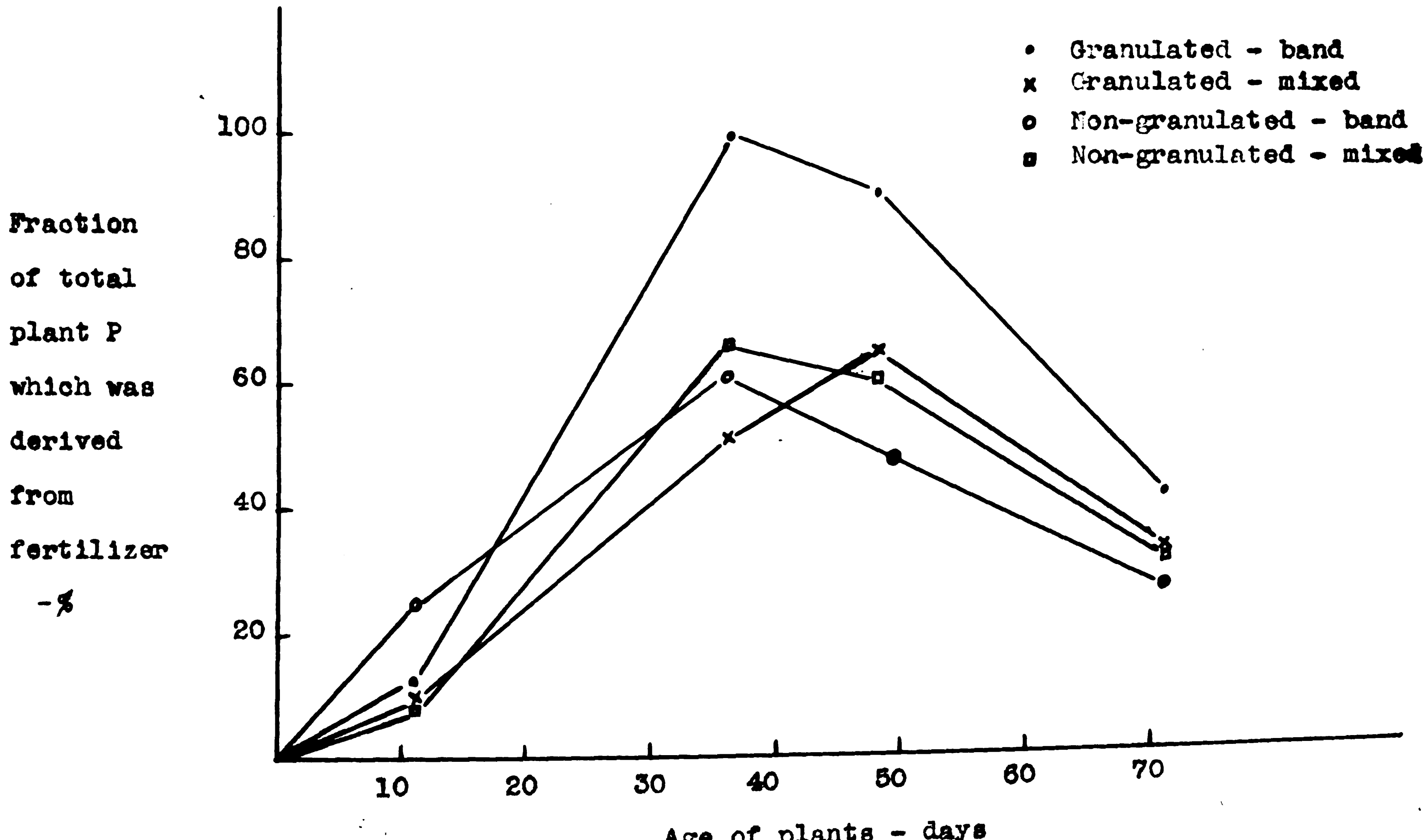

Fig. 8 Composition of plant phosphorus with respect to source for beans grown on Miami soil.

in the total phosphorus of the wheat was lower for band placement than for mixed placement on both soils, while the total plant phosphorus concentration was lower for band placement for wheat only on the Conover soil. This situation probably results from the difference in the original available phosphorus levels of the two soils.

It may be noted from Table XVI that on the second sampling date (plant age - 36 days) over 90 percent of the total phosphorus in wheat was from the fertilizer when placed in bands. When the fertilizer was mixed with the top four inches of soil, about 75 percent of the phosphorus in wheat came from the superphosphate.

Beans, on the average, were not quite as effective in the utilization of fertilizer phosphorus and in three instances the peak utilization appeared on the third sampling date instead of the second. The average top utilization percentage for beans was 87 percent on Conover soil, and 81 percent on the Miami. These peaks are appreciably lower than those for wheat and it appears that the greatest utilization for both crops is somewhat higher on Conover than on Miami soil. This difference is undoubtedly due to the fact that Miami soil has about 10 percent higher "fixing" capacity than the Conover soil.

As seen from Tables XVI and XVII and Figures 5, 6, 7 and 8, the effect of granulation on the percentage of plant phosphorus derived from the fertilizer was inconsistent, but in general granulated material produced slightly higher results on the final sampling date.

D. Observations of fertilizer - root relationship

Concentration of roots in bands. The use of rather heavy application in band placement made it possible to inspect the band after the plants were harvested. It was noted that there was a very heavy concentration of roots growing within the band of fertilizer material. Good distribution of roots outside the band was also noted. It was impossible to ascertain when the heavy concentration of roots in the bands developed, but since the soil phosphorus levels indicated an early dissolution and fixation of the fertilizer phosphorus, it would seem probable that this concentration of roots did not develop until after a major portion of the fertilizer phosphorus had dissolved and was "fixed". It is extremely difficult to decide whether the effect was due to chemotropism or simply to the fact that the roots were following the path of least physical resistance.

The fertilizer band probably provided the path of least physical resistance for two reasons. First, although extreme care was taken to avoid compression of the soil, some probably did occur when the depressions were formed for the fertilizer. Secondly, the dissolving of phosphate material might leave pores for root elongation and enlargement. Also, in the case of the granulated material, the average size of the particles was much larger than the average size of the soil particles and as such would cause the band to provide a more porous medium for growth than would the surrounding soil. It was observed that the concentration of roots in the bands of granulated material was greater than in the bands of non-granulated material.

Photographs were taken of the roots in the fertilizer bands and are included here as Figures 9 and 10. In Figure 9 there is evidence of heavy accumulation of bean roots in a band of superphosphate. It may be noted that the soil is massive in structure. The size of some of the bean roots found in the fertilizer band can be seen in Figure 10. The two large roots shown perpendicular to the stem were in the band of fertilizer. The presence of fertilizer granules clinging to branches of the main roots can also be noted.

Contact of roots and fertilizer particles. Microphotographs were made of plant roots which were recovered from the bands in an attempt to show more clearly the close contact of the fertilizer particles with the plant roots. These photographs are presented as Figures 11-19.

Figure 11 shows a bean root in very intimate contact with several granules of granulated superphosphate. Some rootlets are shown growing into and through the superphosphate granules. Whether this penetration occurred before or after the dissolution of the major portion of the easily soluble phosphate salt cannot be ascertained. The large granule in the center of the photo apparently caused a bending of the root branch going toward the upper right hand corner of the photo. Multiple fine rootlets are shown going into or around each of the granules. It is interesting to note that soil particles are not clinging

Fig. 9

Accumulation of roots of bean plant in band of granulated superphosphate. (Miami soil)

Fig. 10 Large bean roots growing in band of granulated superphosphate. (Conover soil)

Fig. 11 Weathered granules in intimate contact with root of bean plant.

Fig. 12 Particles of non-granulated superphosphate adhering to wheat rootlets.

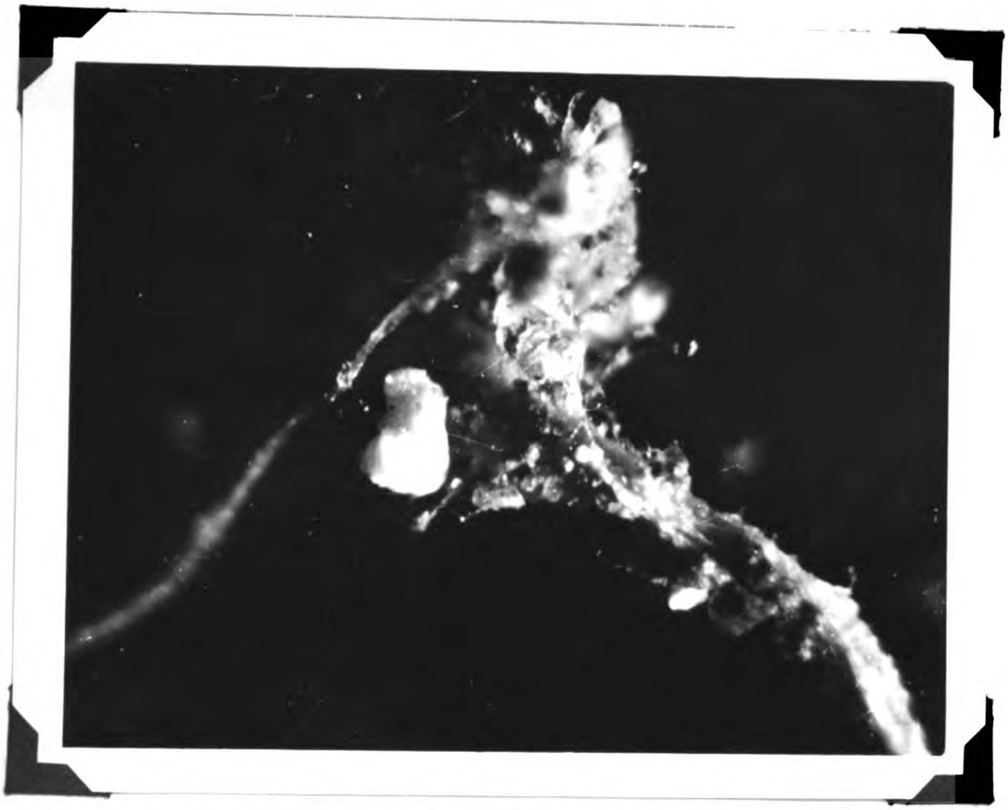

Fig. 13 Contact between bean root and granule of superphosphate. Note enlargement of root at contact.

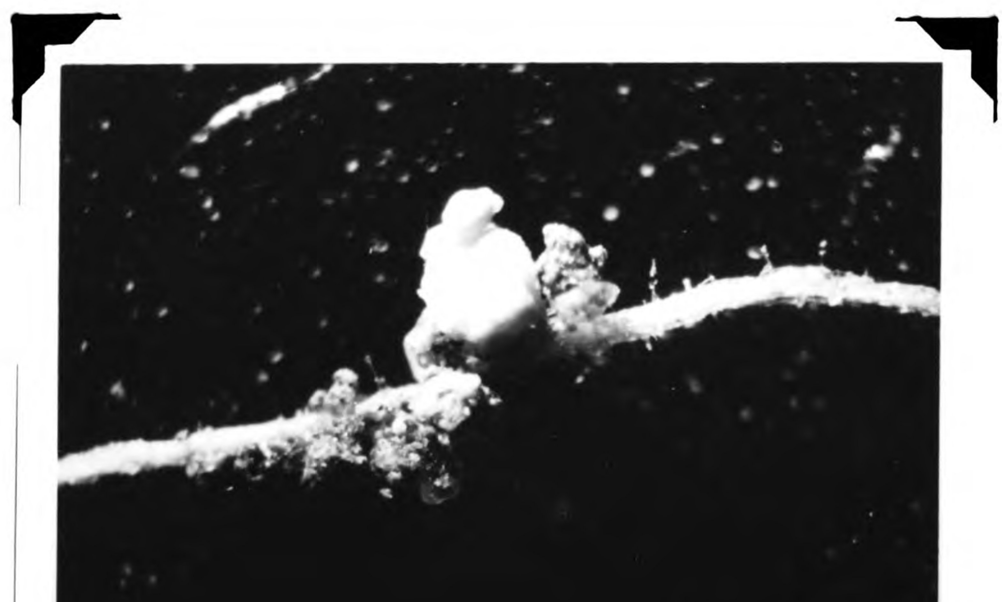

Fig. 14 Root passing through eroded-out cavity of granule.

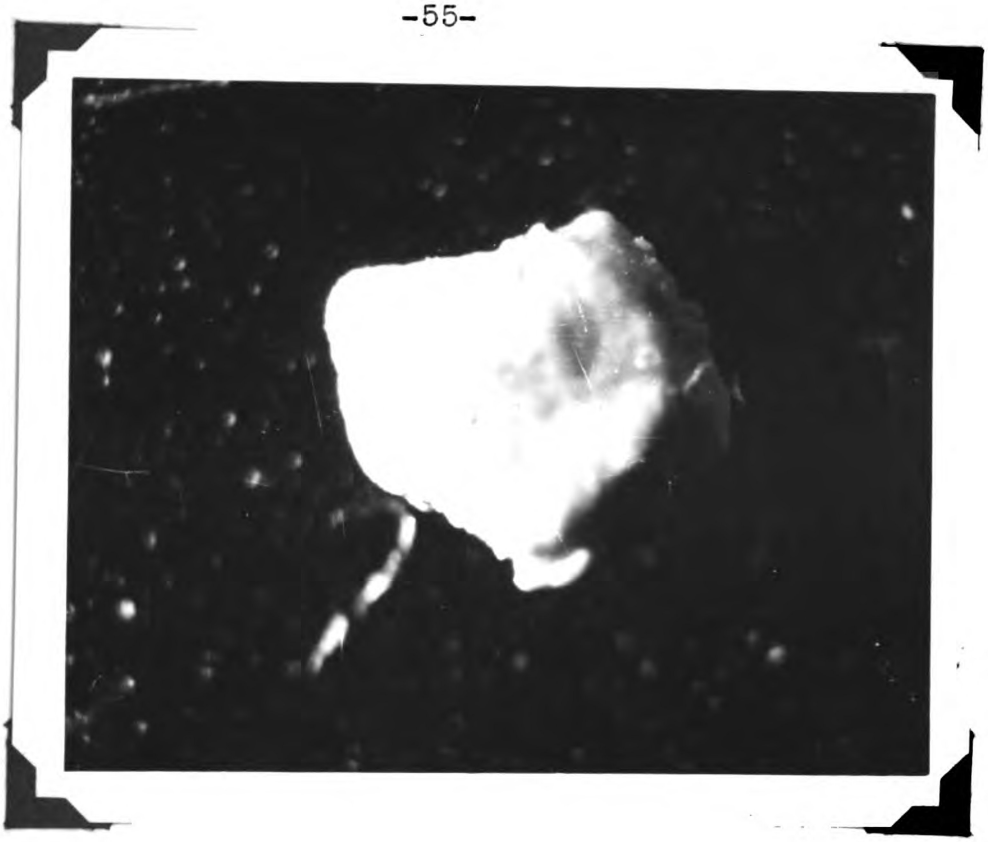

Fig. 15 Granule which had not been in soil.

Fig. 16 Cluster of several granules. Note erosion of large granule on right.

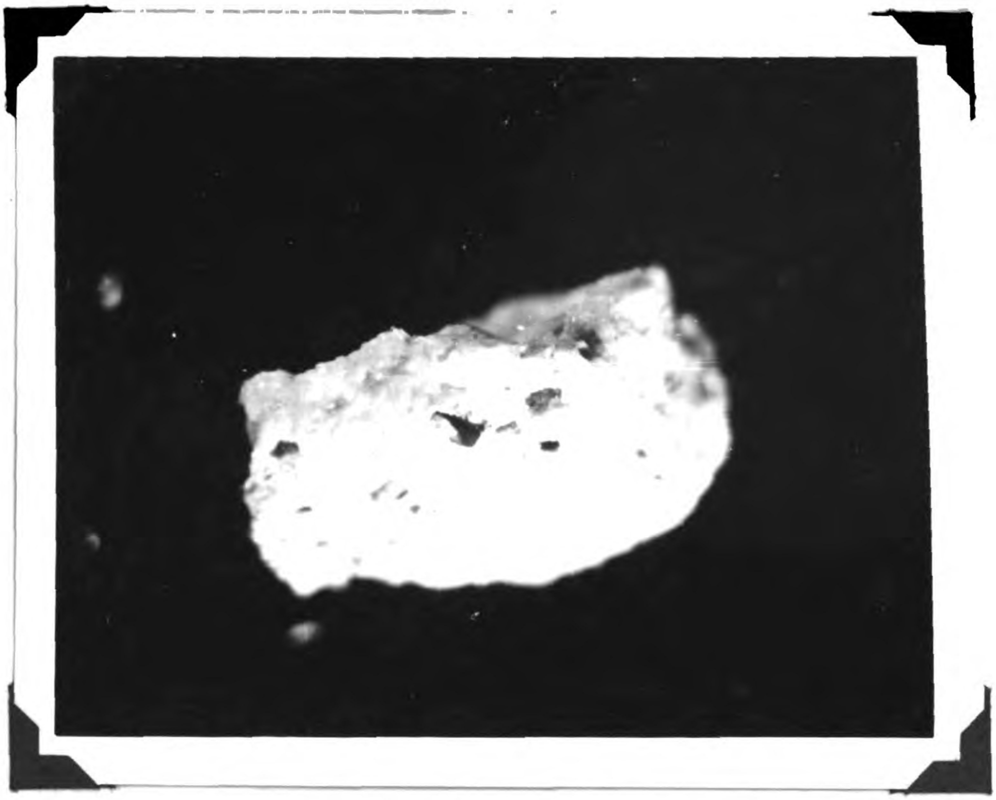

Fig. 17 Granule removed from band. Note effect of dissolution.

Fig. 18 Granule removed from band. Note effect of dissolution.

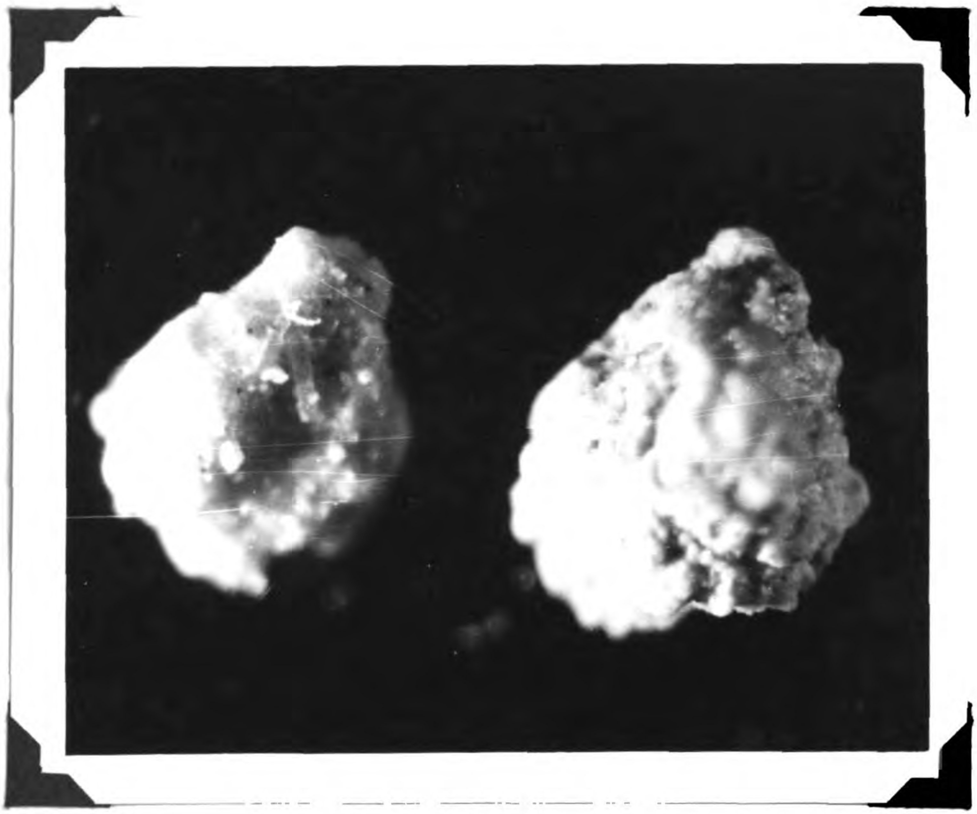

Fig. 19 Two granules removed from band. Note difference. A small root is seen in cavity of granule on left.

to the root in a similar manner.

In Figure 12 a wheat root is shown removed from a band of non-granulated superphosphate. The population of rootlets found on the roots recovered from the band was extremely dense. Practically every rootlet present has attached to it one or several particles of superphosphate. The two large particles shown (upper left and lower center) were macroscopically identified as soil particles rather than superphosphate. Study of the picture indicates that some of the roots are visible in outline in the interior of the particle.

A large granule just slightly below the focus of the camera is evident in Figure 13. The large root shown extending from the lower right hand corner is in contact with it and possibly growing into it. The root appears to be enlarged at the point of contact. The smaller granule at the center of the picture is attached through fine rootlets to both of the large roots shown.

Figure 14 shows a large root passing through an eroded cavity in a single granule. Both the white masses on opposite sides of the root are of the same fertilizer granule and are connected under the root. It is also possible to see fine rootlets growing into the cavity in the portion of the granule shown above the root.

The manner in which fertilizer particles eroded in the soil is presented in Figures 15, 16, 17, 18 and 19. In Figure 15 a granule is shown which had not been in the soil and is in its original condition. The surfaces are not entirely smooth and regular, but a few small depressions and partition planes are visible. Figures 16, 17, 18 and 19 illustrate granules recovered from the soil. The particles shown in these figures illustrate several types of dissolution but it is apparent in each case that the dissolution was not limited to the external surface of the particle. As shown by the chemical analysis data, about two-thirds of the phosphate had dissolved from these particles, hence the residue was probably essentially gypsum.

Figure 16 shows a cluster of several large particles and a number of small ones about a plant root. Some soil particles are also present which may be distinguished by their darker color. The large granule at the right shows appreciable internal dissolution.

<u>Changes in phosphorus content of superphosphate</u>. Duplicate samples of the materials recovered from the soil were analyzed for total phosphorus to determine the effect of incubation in the soil on the analysis of the materials. These samples were composites of material collected from both soils. The pots from which they were collected had grown both crops. The values are reported in Table XVIII along with the original phosphorus contents.

TABLE XVIII

EFFECT OF ONE SEASON IN SOIL ON THE P_2O_5 CONTENT OF SUPERPHOSPHATE

Material	percent P_2O_5 before	after	difference
Granulated super	20.7	6.1	14.6
Non-granulated super	18.4	5.2	13.2

The total phosphorus content changed about the same amount in both states of aggregation. Available phosphorus content of the extracted samples was not determined. The total phosphorus data indicate that granulation had no appreciable effect on the phosphorus remaining after one period of plant growth.

This is the same conclusion made by Sayre and Clark (18) who made a test of this sort in 1937. However, these investigators found there was very little change in the available phosphorus level of the material even after one year. The soil used was Ontario loam with a pH of 6.9. No plants were grown on the fields where the trials were made and the precipitation during the period of the experiment was not reported.

SUMMARY

A greenhouse experiment was conducted to test the effect of granulation and placement on the efficiency of uptake of phosphorus from superphosphate. Conover loam and Miami sandy clay loam soils were used and field beans and spring wheat were grown as indicator crops.

Both soils were relatively high in available phosphorus before the fertilizer applications were made. Phosphate fixation studies showed that the two soils differed appreciably in their ability to fix phosphates. The "fixation" by Miami soil was appreciably greater than by the Conover soil.

The growth of the crops was found to have very little effect on the available phosphorus levels of the soils. The only general trend noted was the reduction in the available phosphorus level between the first and second sampling dates. This fact indicates the completion of the dissolution of the fertilizer phosphorus and its conversion to a non-extractable form.

Yield and plant height data failed to reveal any statistically significant difference due to placement or granulation. However, it was observed that mixed placement gave slightly higher yields in more cases than band placement. The difference was very small. In the comparison of granulated and non-granulated material, the difference was variable and very little can be deduced from the data.

Differences due to placement did show up by measuring the radioactive phosphorus content of the plant tissue, and in the percentages of plant phosphorus derived from the fertilizer. Band placement resulted in higher fertilizer phosphorus contents in all cases except that of the first sampling of wheat (plant age - 11 days). The effect of granulation on these parameters was thoroughly inconsistent, and although no analysis of variance was made of these data, it was concluded there was no significant difference due to granulation.

Some microphotographs are presented to illustrate the characteristics of the dissolution behavior of the superphosphate granules, and to indicate the intimate contact between the granules and the plant roots. No attempt was made to determine just when the high frequency of intimate contact between the roots and fertilizer particles developed, but it is believed that this occurred after the major dissolution rate of the monocalcium phosphate had passed.

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