THE AVAILABILITY OF PHOSPHORUS FROM VARIOUS BIOLOGICAL RESIDUES AS A SOURCE OF PHOSPHORUS FOR SUCCEEDING CROPS

by

Raymond W. Miller

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Raymond H. Miller

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ABSTRACT OF THESIS

Raymond W. Miller, THE AVAILABILITY OF PHOSPHORUS FROM VARIOUS BIOLOGICAL RESIDUES AS A SOURCE OF PHOSPHORUS FOR SUCCEEDING CROPS. Master's thesis, Department of Agricultural Chemistry and Soils, University of Arizona, 1953.

Phosphorus is one of the important elements needed for plant growth and one that is often limiting in soils. The need for expensive fertilizers has required that the phosphorus-fertility value of the large quantities of crop residues plowed under each year be determined. Therefore, studies were made to determine the availability of phosphorus from crop residues as influenced by the phosphorus content of the residue, the kind of biological residue, the rate of application of residue, the available native-phosphorus status of different soils, the chemical fixation of soils, and the rate of decomposition of the residue in the soil.

A rather high proportion of the phosphorus in a succeeding crop may be derived from crop residues incorporated into the soil each year. It was found that the phosphorus available from a residue in a phosphorus-poor soil is directly proportional to the percentage phosphorus in the residue. However, on a phosphorus-rich soil the availability of phosphorus from the residue is more dependent upon the total phosphorus added. Of the three types of biological residues studied, the phosphorus of mature barley straw was slightly less available to rye grass than was that of fungal or algal cells. The phosphorus of crop residues low in phosphorus furnishes a higher percentage to rye grass on soils having an intermediate amount of available phosphorus than to rye grass on soils of very high or very low phosphorus content. Within one week after treatment, the phosphorus of algal cells was as available to rye grass on phosphorus-poor soil as on silica sand. Phosphorus taken up by rye grass from the residues low in phosphorus is inversely proportional to their rate of decomposition.

INTRODUCTION

The availability of soil phosphorus to a crop has long been of concern to the agriculturist. Primitive Indians and early Europeans used many forms of phosphorus-rich substances, such as fish and bones, as an aid to plant growth. By the middle of the 17th century, commercial phosphate fertilizer was introduced.

Today, the fertilizer industry of the United States involves millions of dollars a year in the production and sale of phosphate fertilizers to supply growing crops with sufficient phosphorus. There are many opinions regarding the form of phosphate that is most suitable as a fertilizer source for the growing crops. Recommendations include _inorganic_ fertilizers, such as superphosphate and ammonium phosphate, and _organic_ fertilizers of which manures and crop residues (or green manure crops) are the most common. Certainly comparisons of these two forms to supply available phosphorus to plants cannot be made on the same basis. Their relative effectiveness is dependent upon many soil factors. Moreover, the form used is often dictated by economic circumstance. Even other factors which the farmer controls, such as liming and adding nitrogen compounds, will have varied effects on phosphorus availability (26).*

The consideration of the availability of phosphorus from organic fertilizers is important since some crop residues nearly always remain

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*Parenthesis indicate the number of the bibliographical listing of the reference.

on the land after harvest. These crop residues constitute the greatest single added source of phosphorus for succeeding crops. The importance of crop residues as a source of plant nutrients may well be the determining consideration in a choice of crops for rotation. The benefits which crops derive from these residues will greatly affect, in most cases, the amount and type of supplemental fertilization needed for optimum growth of succeeding crops.

One of the primary considerations in evaluating an added material is its phosphorus content. A material low in phosphorus would very likely be much less valuable for supplying phosphorus to a succeeding crop than a material high in phosphorus, other factors being equal. The phosphate content of plant materials may vary between wide ranges. Some plants require a higher phosphorus level than others; plants also vary in their ability to obtain phosphorus from the soil during growth. For example, Bauer (2), states that sweet clover possesses remarkable feeding powers for the phosphorus of rock phosphate. And, according to Russell (23), different crops show remarkable variation in the ability to utilize naturally occurring phosphates of the soil. The phosphorus content of one crop residue may therefore be twice the phosphate content of another crop residue on an equal dry weight basis, though they grew on the same soil.

The percentage of phosphorus in a crop, however, is not the only important factor in its usefulness as a phosphorus source to succeeding crops. The rate at which the phosphorus becomes available upon the decomposition of the residue must be taken into consideration. The absorption of the phosphorus from green manure (9), and logically also that from algae and fungi (11), appears to vary inversely to the phosphorus-supplying power of the soil. Thus a crop grown on a soil low in available phosphorus would tend to obtain a larger percent of its phosphorus from the added residues than a crop grown on a soil rich in available phosphorus. Fuller and Dean (9) report another interesting effect--that layering of the green manure (simulating plowed-under material) appeared to favor the uptake of phosphorus. A similar influence was noticed by Welch, Hall, and Nelson (29) who studied the early absorption of phosphorus from inorganic fertilizers.

The phosphorus of the crop residues must be released by decomposition in order to be available to a growing plant. It is known that different materials may decompose at different rates. Waksman and Tenney (28) indicate that the age of the plant material added to the soil affects the rate of decomposition. They state that the younger and less mature the material, the more rapidly it is decomposed. Maynard (19) reports a similar relationship with sweet clover. Fuller and Rogers (11) found that young barley hay furnished a greater percentage of phosphorus to the succeeding crop on a single soil than did mature barley straw.

The decomposition of organic material is accomplished by the soil microorganisms such as bacteria and fungi. They increase to large numbers and activity when organic matter is plowed under or other sources of energy are added to the soil. Algae may also utilize the released minerals and carbon compounds. The relationship of these soil microorganisms to the available phosphate in a soil is in part controversial. It has been fairly well established that the mineralization of phosphate from biological residues is a continuous process, and several investigators (14, 25) have presented data to indicate that there may be ample time between the processes of mineralization and microbial immobilization for the growing plant to absorb the released phosphorus. Another investigator (22) has found indications that some organic phosphate compounds may be available to plants without change, although it is generally accepted that phosphate assimilation by plants is by way of ionized ortho phosphate.

What happens to the mineralized phosphate? It is known that much of the mineralized phosphate is fixed in some manner by the soil in a form not readily available to the plant.

Sing Chen Chang (4) states that considerable organic phosphorus is synthesized by microorganisms in early stages of decomposition, and that this organic phosphorus is synthesized from inorganic phosphorus. This would indicate that biological fixation occurs to a large extent in the presence of organic matter low in phosphorus. A similar assumption is made by Pearson, Norman, and Ho (21). They assume from their results of a study of the mineralization of nucleic acid is due to immobilization by the microbial population.

However, Dyer and Wrenshall (6) reached a different conclusion from studies on the decomposition of yeast nucleic acid, calcium uridylate, soil nucleotide, guanylic acid, adenylic acid, cytidylic acid, and manure in the soil. Using the phosphorus soluble in pH 3 sulfuric acid as a measure of the available phosphorus in a soil, they found that almost complete recovery of added inorganic phosphate was obtained on extraction of the samples with acid stronger than pH 3. Because of these results, they concluded that reversion, and not biological fixation, caused a decrease in inorganic forms of phosphorus added to the soil. It is likely, however, that phosphorus from biological tissues could be almost completely recovered by means of such strong acid treatment. Thus the conclusion, that the added phosphorus is made unavailable by reversion and not by biological fixation, does not appear to be substantiated.

This apparent conflict between the findings of the above investigators on the fixation of mineralized phosphorus by biological or by chemical means has been reconciled by Fuller and McGeorge (10). They show that without the presence of carbonaceous material there is no appreciable biological immobilization of phosphorus. Also, Fuller and Rogers (12) state that the rate of utilization of phosphorus from algal cells was influenced to a greater extent by microbial than by chemical factors.

It is probable that both biological and chemical fixation of mineralized phosphorus occur during decomposition of organic matter. The proportion fixed by each method would, in part, depend upon biological activity, the C/P ratio of the material, and the relative quantities of the ion(s) causing chemical fixation. In any case, the effect of biological fixation of phosphorus added to the soil may be of great importance in soils low in available phosphorus.

The availability of the added phosphorus may not be the most important consideration in the case of all added organic residues. In addition to supplying phosphorus directly to plants, crop residues or other decomposable organic materials may contribute to the phosphate economy of the soil by making native soil phosphorus more available to plants. Dalton, Russell, and Sieling (5) state that organic matter added to the soil may be effective in increasing the availability of soil phosphate. They further state that easily decomposable organic matter is more effective in this respect than are organic substances that have a slower rate of decomposition. The activity of organic matter in making soil phosphate available may be attributed to the ability of certain metabolic products of microbiological decomposition to form stable complex molecules with Fe and Al. These elements are believed to be responsible for phosphate fixation in acid soils. The fact that they found easily decomposable organic matter more effective than difficultly decomposable materials can be explained by the above suggestion. The increased biological activity on such materials would cause an increase in these certain metabolic products and thus affect a more complete fixation of Fe and Al of the soil.

In the arid soils of the West, however, Ca probably is responsible for most of the chemical fixation of phosphorus. The large quantity of calcium carbonate in many of the soils has caused much attention to be focused on the calcium-phosphorus relationship. It is commonly believed that calcium may precipitate the soluble phosphate of the soil solution as some insoluble form of calcium phosphate. The effect of organic matter on this phosphorus fixation by calcium has been studied by many investigators. McGeorge and Breazeale (18) state that the carbon dioxide released during the decomposition of organic material makes the soil calcium phosphate more soluble. In a few cases they have reported a ten-fold increase in the available phosphorus of the soil solution due to the presence of carbon dioxide, although smaller increases are more commonly found. The exact mechanism of carbon dioxide in making calcium phosphate more soluble has not been determined, although McGeorge and Breazeale (18) state that soil pH is a determining factor. They report that "in order for carbon dioxide to increase measurably phosphate solubility in calcareous soils, it must be present in sufficient amounts to reduce the reaction below neutrality or to approximately pH 6.2-6.4."

The amount of carbon dioxide in the soil due to the decomposition of organic material is dependent upon the quantity and rate of decomposition of the organic materials present. The rate of decomposition is in turn partially dependent upon the nutrient supply available for the decomposing organisms. Organic matter added to the soil often contains a wide source of nutrients which is usually sufficient for the needs of microorganisms in decomposition. The nitrogen content, however, is very often insufficient for the requirements of the microorganisms. Such a deficiency restricts the rate of decomposition of the crop residue, which in turn may result in a reduction in the rate of release of phosphorus from the crop residue. Waksman (27), in experiments with the roots of several different plants, claims that only when the nitrogen content is 1.7 percent or higher is there sufficient nitrogen in the root materials to supply the requirements of the microorganisms for cell synthesis. If the nitrogen percentage of the material is lower than this minimum, then nitrogen from the soil may be used by the soil flora, which would thus be in competition with a growing crop for soil nitrogen.

Fuller and Rogers (11) present an interesting nitrogen-phosphorus relationship. They state that: "(1) Nitrogen added at the rate of 100 pounds of N per acre did not affect the percent phosphorus found in the plant that was derived from barley straw or roots, (2) The addition of oat straw, with a wide C/N and C/P ratio, significantly lowered the percentage phosphorus in the plant derived from liquid phosphoric acid and barley hay and straw. Nitrogen application at the rate of two percent of the straws did not influence this utilization, (3) Nitrogen markedly increased yields of grass but lowered the percent phosphorus of the grass, and (4) Nitrogen depressed the total phosphorus taken from all sources when applied to the medium mature hay and mature straw treatment. When applied to more slowly available carbon sources such as roots and extracted straw from mature barley, nitrogen tended to improve total phosphorus uptake."

The effect of organic matter on the soil is not restricted to nitrogen or phosphorus availability, though. It may affect soil structure, moisture content, and numerous other environmental conditions.

The evaluation of biological residues is, therefore, a problem that is of economic concern to many farmers. Tons of organic matter as crop residues or green manure crops enter the soil each year. The primary evaluation of the effect or efficiency of various materials as a source of nutrients, in the past, has been based upon an increased or decreased crop yield. Earlier experimenters had no method of distinquishing between the phosphorus of the soil and the phosphorus from the biological residues after the residues were incorporated into the soil. The discovery of induced radioactivity by Curie in 1932 introduced a new tool for research in the chemistry of biological systems.

Within a year or two, it was discovered that radioactive isotopes of almost any element could be produced by bombardment with high energy protons, deuterons, alpha particles, or neutrons. The cyclotron was able to produce radioactive isotopes of the physiologically essential elements in sufficient quantities to permit limited experimentation with growing plants, using the radioactive isotopes as tracers. The construction of the atomic pile, during World War II, made possible the production of isotopes in quantities sufficient for wide-scale research.

The detection of radioactive elements can be made by a Geiger-Muller counter, which satisfactorily measure 10^{-7} to 10^{-13} millicuries. One curie of any radioactive material is that quantity of the element that undergoes the same number of disintegrations per unit time as one gram of radium, not including its radioactive daughter elements. Thus one curie is equivalent to 3.7×10^{10} disintegrations or particles per second. Potassium, for example, can be measured in extremely small amounts (10^{-17} grams) (24). Hence the measurement of various isotopes can be relatively accurate. In order to have sufficient disintegrations for accurate counting, the half-life of the isotope(s) used must be taken into consideration when planning experimentation.

The application of tracer elements in research depends upon quantitative determination in terms of change in specific activity. The specific activity of any radioactive material is defined as the number of disintegrations per unit weight of material per unit time. The change in specific activity from dilution with the non-radioactive isotope of the element is the basis of most phosphorus uptake experiments.

Any material containing both non-radioactive and radioactive phosphorus will have a definite radioactivity per unit weight of phosphorus at any particular time. If this material is then added to a soil upon which a crop is to be grown, the radioactivity of a unit weight of phosphorus in the crop indicates the amount of phosphorus derived from the added material. Thus, if the phosphorus analyzed from the crop is only one tenth as radioactive per unit weight of phosphorus as that in the added material, both samples measured at the same time, then only one tenth of the phosphorus in the plant came from the added material.

In this investigation, by adding the radioactive isotope of phosphorus, P^{32}, to the biological materials to be incorporated into the soil, it was hoped to determine the relative percentage of phosphorus from the various biological materials available to crops.

This information indicates the relative values of various plant residues for supplying phosphorus to succeeding crops. From such knowledge, better evaluation may be made of crop rotation practices, fertilizer requirements for succeeding crops, and the problems of whether to sell or to plow under crop residues, such as grain straw.

EXPERIMENTAL METHODS

Preparation of Labeled Plant Materials

The various crops used were grown in pure quartz sand in steel trays (6" x 24" x 48") coated with black rubberized Stelecote* paint. The following crops were planted: Chilean alfalfa, Aravat barley, White Dutch clover, flax, hegari, Romaine lettuce, Marglobe tomatoes, and Baart wheat. Seeds were treated with Ceresan before planting.

All crops were subirrigated with a balanced nutrient solution except for phosphorus which was omitted. Radioactive phosphorus in solution was added periodically to supply the desired final level of phosphorus in the plant residues. Subirrigation was done usually twice daily for about 10-15 minutes each irrigation and allowed to drain.

When mature, the plants were cut and the fruit, grain, etc., were separated. The roots were immediately washed free of sand and possible adhering phosphorus. All parts were dried in an oven at about 65° C. for 48 hours and then ground to pass through a 20 mesh screen. Each ground material was thoroughly mixed and proved to be very uniform as indicated by agreement of the analyses of duplicate samples made at random on each material.

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*Trade-name

Preparation of Labeled Algae

Green algae were obtained from a damp garden soil and isolated by successive dilutions in Bristol's sodium nitrate solution (3). The algae proved to be Palmela of the Chlorophyta division.

Bristol's media was prepared containing no phosphate. The media was then divided into 1½ liter portions and put into 40 one-gallon jars. 0.030 grams of irradiated KH_2PO_4 was added to each jar and the solutions innoculated with algae. Muslin was clamped over the mouths of the jars to keep out dust and dirt. The jars were placed in the greenhouse and allowed to incubate for 31 days.

The algal material was separated from the solution by centrifuging, washed four times with distilled water, two times with 0.01 N phosphoric acid, and then five times with distilled water. The last rinse showed no trace of phosphorus. The algae were then suspended in distilled water by stirring in a Waring blender. Care was taken to prevent operating the Waring blender so long that it over-heated the mixture. The suspension was then diluted to a volume of two liters and shaken until well mixed.

Dry weight algae determinations and phosphorus determinations were made on the suspension. The dry weight analysis showed less than 0.4 percent variation between three 10 ml. aliquots, so the suspension was considered sufficiently well mixed. The suspension was kept stored in a refrigerator until used. The 60 liters of solution yielded about 46 grams of algae on an oven-dry weight basis.

Preparation of Labeled Fungi

Pure cultures of Penicillium humicola and Aspergillus niger were cultivated on Czapek's agar medium (8). The organisms were cultured on agar slants in 800 ml. small-mouthed bottles.

When the cultures were sufficiently numerous for use, each gallon jar containing 500 ml. of sterilized Czapek's aqueous medium containing no KH_2PO_4 was innoculated with one of the fungi cultures by means of a heat-sterilized wire loop. About 0.07 grams of irradiated KH_2PO_4 was added to each jar and the jars kept at room temperature (20-24° C.). The fungi were harvested twelve days later, and rinsed with distilled water several times. The fungal mats were then rinsed in 0.01 N H_3PO_4 and again rinsed with distilled water until a test on the rinse for phosphate was negative. The rinsed fungal mats were allowed to stand in distilled water in a refrigerator over night. Any small pieces left in the solution were settled in a centrifuge. The entire yield of fungi was then rinsed and laid out to dry on paper towels. When dry, the material was ground to pass through a 40 mesh screen and bottled for later use.

Preparation of Radioactive Phosphoric Acid Solutions

Radioactive phosphoric acid solutions were prepared by dissolving irradiated KH_2PO_4 in sufficient distilled water so that the aliquot required for each sample would be of a convenient volume.

CHEMICAL ANALYSES OF THE MATERIALS USED

Chemical Analysis of the Biological Materials

The total phosphorus of the biological materials was determined colorimetrically as molybdivanado-phosphoric acid (15); carbon was determined by the wet oxidation method (1); and nitrogen was determined by the standard micro-Kjeldahl method. The nitrogen determinations of the plant materials were made on samples reground to pass through a 60 mesh screen.

Chemical Analysis of Soils Used

The available phosphorus of the soil is defined as that soluble in CO_2-water extracts according to McGeorge (17). Carbon was determined by the wet oxidation method (1), and nitrogen by the standard Kjeldahl method. Carbonates were determined by the gasometric procedure as given by Emerson (7).

Measurement of P^{31} and P^{32}

The measurement of the uptake of phosphorus by rye grass from the treatments added to the soils was made according to the method suggested by MacKenzie and Dean (16).

Method for Calculating the Percent Uptake of Phosphorus

The intensity of radioactivity of the phosphorus from the plant material was determined by a Geiger-Muller counter and then expressed in terms of counts per second, corrected for the count of a control and background. This activity was divided by the number of milligrams of phosphorus in the material to give the net specific activity of the phosphorus. The net specific activity of the phosphorus from the plant material divided by the specific activity of the phosphorus from a sample of the treatment and multiplied by 100 represents the percent uptake. This method is the same for all problems involving isotopically-labeled substances and is based upon the principle of isotope dilution.

Apparatus for Measuring CO_2 Evolution as an Indication of Decomposition

The CO_2 evolution from 100 grams of air-dry soil along and with the addition of 1 gram of plant materials being used for phosphorus uptake studies, was ascertained at intervals for a period of 21 days (20). The materials were ground to pass a 40 mesh sieve and samples of 1.000 gram weight weighed out. The material was mixed with the soil and then the mixture brought to 60 percent of the normal field moisture-holding capacity. The soils were incubated at 26° C. in openmouth quart bottles closed with rubber stoppers each having a broken thermometer tube in it to allow a very low amount of air exchange through the capillary. The CO_2 was absorbed by standard alkali contained in short wide test tubes (approx. 7/8 x 5") resting on the soil. Prior to titrating, the bottles were briskly aerated for 15 minutes into Truog towers containing standard alkali. The combined alkali from the tower and the test tube was titrated in one operation after the carbonate had been precipitated with excess neutral barium chloride.

EXPERIMENTAL MATERIALS

Composition of Biological Materials

The total phosphorus of the fungi, algae, and barley used in the total uptake and uptake rate experiments is given in Table 1.

The total phosphorus, carbon, and nitrogen contents of the biological materials used in the phosphorus uptake from crop residues are given in Table 2. Also given is the analysis of the oat straw used to supply organic matter in some pots to determine the effect of organic matter on phosphoric acid uptake and on crop growth.

Composition of the Soils Used

The soils for these experiments were selected mainly on a basis of agricultural significance, phosphate-supplying power, and, to a lesser degree, texture and organic matter content. The chemical analyses of the soils are given in Table 3.

TABLE 1. TOTAL PHOSPHORUS (P) OF BIOLOGICAL RESIDUES USED IN TOTAL AND RATE UPTAKE STUDIES

MATERIAL	TOTAL PHOSPHORUS percent	MATERIAL	TOTAL PHOSPHORUS percent
Fungus 1 (*P. humicoli*)	0.627	Mature barley straw 1	0.575
Fungus 2 (*P. humicoli*)	0.683	Mature barley straw 2	0.421
Fungus 3 (*A. niger*)	0.639	Mature barley straw 3	0.401
Fungus 4 (*A. niger*)	0.561	Mature barley straw 4	0.395
Fungus 5 (air contaminants)	0.625	Mature barley straw 5	0.237
Algae (Palmela sp.)	1.018	Mature barley straw 6	0.186
Mature barley straw	0.484		
Mature barley roots	0.308		

TABLE 2. CARBON, NITROGEN AND PHOSPHORUS CONTENT OF MATURE CROP RESIDUES

CROP RESIDUE	CARBON	NITROGEN	TOTAL PHOSPHORUS	C/N RATIO	C/P RATIO
	Percent	Percent	Percent		
Alfalfa hay	37.1	4.63	0.17	8.0	222
Alfalfa roots	41.5	4.29	0.20	9.7	206
Barley straw 1a	34.8	3.59	0.17	9.7	203
Barley straw 2a	33.4	4.25	0.16	7.9	212
Barley straw 3a	36.6	3.47	0.14	10.6	271
Barley straw 4a	36.2	3.16	0.13	11.5	288
Barley straw 5a	35.5	3.50	0.11	10.1	316
Barley roots 1a	36.5	2.27	0.15	16.1	248
Barley roots 2a	38.8	2.18	0.13	17.8	296
Barley roots 3a	41.4	2.52	0.12	16.4	345
Barley roots 4a	33.3	1.99	0.11	16.7	305
Barley roots 5a	33.5	1.97	0.10	17.0	349
Clover hay	42.1	4.98	0.18	8.5	235
Clover roots	41.2	4.16	0.17	9.9	244
Flax tops	38.3	3.53	0.11	10.9	348
Flax roots	36.0	4.32	0.12	8.3	297
Hegari stalks	39.7	1.82	0.08	21.8	496
Hegari roots	41.0	2.42	0.10	16.9	320
Lettuce tops	37.7	4.48	0.32	8.4	117
Tomato tops	36.8	3.99	0.22	9.2	171
Tomato roots	34.5	3.08	0.18	11.2	188
Wheat straw	35.6	2.24	0.11	15.9	307
Wheat roots	40.1	2.87	0.13	14.0	262
Oat straw*	41.5	0.36	0.02	115.3	2075

*Contains no radiophosphorus

TABLE 3. SOILS USED IN TOTAL AND RATE UPTAKE STUDIES

SOIL*	DEPTH inches	pH PASTE	CO_2-SOLUBLE PHOSPHORUS ppm	CARBON percent	NITROGEN percent	RATIO C/N	CARBONATE percent
Mohave clay loam	0-6	7.6	0.4	0.95	0.09	10.5	0.13
Pima clay loam	0-6	7.5	8.8	2.38	0.22	10.8	1.57
Tubac sandy loam	0-6	7.5	3.2	0.53	0.04	11.0	0.44
Tucson sandy loam	0-6	7.3	1.8	0.63	0.04	8.0	0.32
Pima sandy loam	0-6	7.2	2.9	0.61	--	--	2.64

* All soils were obtained in the virgin condition.

TREATMENTS

Treatment Used in Rate of Utilization Study

Rye grass was grown in Pima sandy loam and in pure silica sand. The sand cultures were watered with a balanced nutrient solution except containing no phosphorus. One and one-half kilogram porcelain pots were used and contained one kilogram of soil or an approximately equal volume of sand.

When the rye was three weeks old, algae in suspension was pipetted into all pots at the rate of 50 pounds of P_2O_5 per acre.* This was accomplished by having several glass tubes at various depths inserted in each pot at the time of planting. These were removed and rinsed into each pot after the algae application.

Cuttings were made in duplicate at intervals of 1, 3, 7, 14, 21, 28, 35, 42, and 56 days on the soil and on sand at 1, 3, 7, 14, and 21 days after the application of algae. Second cuttings were made 41 days after the first cuttings.

Treatments Used in Total Utilization Studies

All plant residues (barley, wheat, flax, hegari, tomato, lettuce, alfalfa, and clover) were added on a basis of pounds of P_2O_5 per acre. The rates were 25, 50, 100, or 150 pounds per acre. Each treatment was replicated two times.

In selecting the rate of P_2O_5 to add, it is important that the

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*All rates were based on the top acre 6-inch slice of soil and this slice as weighing 2,000,000 pounds.

loss of radioactivity of the phosphorus in the long growing periods of the residue crop and of the rye grass be considered. Approximately 90 to 100 days were required for most of the residue crops to reach maturity. By the time a five weeks-old rye crop could be grown on the plowed-under residues, the radioactive phosphorus added to the residue crop would have lost about nine half-lives. The half-life of P^{32} is 14.3 days. So a unit weight of P^{32} would have only about 0.2% of the activity at the end of these 130 days as it had in the beginning. The specific activity was decreased yet more by dilution of the radioactive phosphorus in the rye grass with non-radioactive phosphorus. It was therefore necessary to add sufficient quantities of residues to insure having measurable amounts of P^{32} in the rye grass.

Another main consideration was to keep the treatments as near to conditions that occur in the field as possible. In some cases, the percentage phosphorus of the residues was low. To obtain the needed activity of the phosphorus in the rye grass, relatively large applications of the residue needed to be added. Thus, application rates were often higher than is practical under field conditions.

The calculated weights of dry materials were weighed out and mixed in one kilogram portions of soil. The soil was then brought to about 60 percent of the field water-holding capacity and seeded to perennial rye grass. Vermiculite was placed on the soil surface to keep the surface moist and help seed germination. They were allowed to grow for about five weeks before the first cutting was made. In the first total utilization study, a second cutting was made at 32 days after the first, and a third cutting was made at 17 days after the second. In the second and third total utilization study only one cutting was made. Further cuttings were omitted because the spring sun made the greenhouse temperature too warm for normal plant growth.

Sufficient nitrogen for decomposition was added in the form of NH_4NO_3. It was added to all pots one week after germination of the rye grass. The purpose was to eliminate nitrogen as much as possible as a limiting element in the decomposition of the incorporated crop residues.

Treatment Used in Decomposition Rate Studies

Because of the consistantly low yields of rye grass and the low available phosphorus it furnishes, Mohave clay loam was used in this study. 1.000 gram of one of each plant residue tested was added to a 100 gram sample of soil and was thoroughly incorporated in it. The soil was brought to about optimum moisture. The procedure given in the section on chemical analysis of the materials was followed completely.

RESULTS

The Availability of the Phosphorus of Fungi

The phosphorus absorbed from the different fungus materials by rye grass varied considereably (Table 5) despite the fact that the materials contained approximatly the same amount of phosphorus and were added to the soil at about the same rate. For example, the phosphorus in the rye grass derived from P. humicoli incorporated in Mohave clay loam was about 35 percent at the time of the first cutting whereas that from A. niger was about 26 percent. The fungus material which furnished the most available phosphorus in one soil was also most available in the other soils. In general, greater absorption took place during the period of time represented by the second cutting than the first.

Absorption of phosphorus also varied markedly with different soils (Tables 4 and 5). The uptake of fungal phosphorus varied indirectly with the amount of available native phosphorus in the three soils studied. The percentage phosphorus in the rye grass derived from the fungal materials added to Mohave clay loam was about twice as high as that from the same materials mixed in Pima clay loam. Pima clay loam is much higher in CO_2-soluble phosphorus than Mohave clay loam. Pima sandy loam was intermediate in CO_2-soluble phosphorus and proved to support rye grass intermediate to the other two soils in phosphorus derived from the fungal materials.

The absorption of phosphorus from crop materials added to a soil

TABLE 4. YIELD AND TOTAL PHOSPHORUS CONTENT OF RYE GRASS ON TREATED SOILS

MATERIAL ADDED	RATE MATERIAL ADDED ON BASIS OF LBS. P_2O_5/A					
	50 lbs.		100 lbs.		150 lbs.	
	Yield†	Total P	Yield	Total P	Yield	Total P
MOHAVE CLAY LOAM						
	gms.	mgm.	gms.	mgm.	gms.	mgm.
1. Fungus (*P. humicoli*)	5.19	7.52	--**	--	--	--
2. Fungus (*P. humicoli*)	5.75	8.01	7.08	10.03	--	--
3. Fungus (*A. niger*)	5.09	7.53	5.95	9.83	--	--
4. Fungus (*A. niger*)	5.02	7.13	6.25	10.42	--	--
5. Fungus*	4.35	5.72	6.00	10.0	--	--
Algae (Palmela sp.)	4.60	5.7	6.00	9.3	7.66	9.1
Mature barley straw	3.56	5.1	5.25	7.4	6.94	11.1
Mature barley roots	5.04	7.1	5.78	8.33	--	--
Control--no treatment	4.42	4.6				
PIMA SANDY LOAM						
1. Fungus (*P. humicoli*)	--	--	--	--	--	--
2. Fungus (*P. humicoli*)	5.18	6.17	5.80	9.1	--	--
3. Fungus (*A. niger*)	4.13	5.83	6.18	9.1	--	--
4. Fungus (*A. niger*)	4.11	4.9	--	--	--	--
5. Fungus*	4.06	5.0	5.44	8.0	--	--
Algae (Palmela sp.)	4.28	5.4	6.24	8.0	7.44	9.1
Mature barley straw	3.33	4.0	4.52	5.3	3.87	4.8
Mature barley roots	2.79	3.1	5.06	5.3	--	--
Control--no treatment	3.30	3.8				
PIMA CLAY LOAM						
1. Fungus (*P. humicoli*)	8.54	19.5	--	--	--	--
2. Fungus (*P. humicoli*)	7.64	20.0	--	--	--	--
3. Fungus (*A. niger*)	8.17	17.7	--	--	--	--
4. Fungus (*A. niger*)	9.59	17.7	--	--	--	--
5. Fungus*	8.36	21.6	--	--	--	--
Algae (Palmela sp.)	8.81	21.2	--	--	--	--
Mature barley straw	7.87	14.9	--	--	--	--
Control--no treatment	7.12	14.2				

*Air contaminants

**No treatments made

†Average of 2 pots; 1 Kg. of soil/pot; total of 3 cuttings; based on oven-dry material.

TABLE 5. PERCENT PHOSPHORUS (P) IN RYE GRASS DERIVED FROM FUNGI, ALGAE, AND BARLEY RESIDUES

	MOHAVE CLAY LOAM			PIMA SANDY LOAM			PIMA CLAY LOAM
	RATE MATERIAL ADDED ON BASIS OF P_2O_5 PER ACRE						
MATERIAL ADDED	50 lbs.	100 lbs.	150 lbs.	50 lbs.	100 lbs.	150 lbs.	50 lbs.
First Cutting							
	percent	percent	percent	percent	percent	percent	percent
Fungus 1 (<u>P. humicoli</u>)	35	—*	—	—	—	—	15
Fungus 2 (<u>P. humicoli</u>)	27	52	—	24	43	—	14
Fungus 3 (<u>A. niger</u>)	26	52	—	26	48	—	12
Fungus 4 (<u>A. niger</u>)	26	45	—	25	—	—	11
Fungus 5 (air contaminants)	21	33	—	19	33	—	9
Algae (<u>Palmela</u> species)	22	27	31	21	35	46	13
Mature barley straw	18	37	47	15	26	44	12
Mature barley roots	16	36	—	12	24	—	8
Second Cutting							
Fungus 1 (<u>P. humicoli</u>)	39	—	—	—	—	—	20
Fungus 2 (<u>P. humicoli</u>)	33	54	—	30	47	—	19
Fungus 3 (<u>A. niger</u>)	35	53	—	29	59	—	17
Fungus 4 (<u>A. niger</u>)	33	47	—	30	—	—	16
Fungus 5 (air contaminants)	31	40	—	34	46	—	17
Algae (<u>Palmela</u> species)	35	58	62	33	50	67	11
Mature barley straw	10	45	49	11	32	44	7
Mature barley roots	10	—	—	9	27	—	6
Third Cutting							
Fungus 1 (<u>P. humicoli</u>)	20	—	—	—	—	—	15
Fungus 2 (<u>P. humicoli</u>)	24	42	—	24	48	—	13
Fungus 3 (<u>A. niger</u>)	25	33	—	18	45	—	12
Fungus 4 (<u>A. niger</u>)	23	38	—	17	—	—	13
Fungus 5 (air contaminants)	22	29	—	16	46	—	12
Algae (<u>Palmela</u> species)	33	33	47	27	55	68	10
Mature barley straw	26	50	65	18	43	—	7
Mature barley roots	—	44	—	13	22	—	5

*No application made

may also be evaluated on the basis of <u>total absorption</u> which is a function of both percent phosphorus derived from an added source and yield of dry material. On a basis of total absorption greater quantities of phosphorus were absorbed by the rye grass from fungal material mixed in Pima clay loam than from that added to either the Mohave soil or Pima sandy loam (Tables 4 and 5). Rye grass grown on Mohave clay loam had a slightly greater yield and also absorbed more phosphorus from the fungal material than that grown on Pima sandy loam.

The rate of application of the fungal material to the soils influenced the absorption from the different sources. More phosphorus was absorbed by the rye grass from the higher than the lower rate of applications. Doubling the rate of application of fungal material more than doubled the amount of phosphorus absorbed from this source. The effect of the rate of application of fungal material on yield was proportionatly greater than that on the percentage phosphorus in the grass derived from this material. For example, yields were more than double in pots receiving fungal material equivalent to 100 lbs. P_2O_5/A as compared with that from pots receiving half this amount. The percentage phosphorus in the grass from pots receiving these two rates, however, differed by less than a factor of two.

<u>The Availability of the Phosphorus of Algae</u>

The phosphorus from algae appeared to be approximately as available to rye grass as that from fungi (Table 5). Yields and phosphorus content of rye grass on alga-treated soil also were similar to those found on fungus-treated soils.

The effect of cuttings on the percentage of phosphorus derived from algal residues varied only slightly from that of fungi (Table 5).

In an experiment to determine the rate at which phosphorus was taken up from algae, the availability of the phosphorus of the algal cells to rye grass was compared in Pima sandy loam and quartz sand. The results (see Fig. 1, Fig. 2 and Table 6) show that the phosphorus uptake from algal residues in both soil and sand increases with time. The phosphorus of the algae was immediately available to the rye grass as shown in sand. The rye grass grown in soil absorbed very little phosphorus from the algae the first few days, but within a week it had taken approximately one-half of its phosphorus from the algae. By the end of 21 days approximately 60% of the phosphorus of rye grass on sand and soil was derived from the algae. This indicates that Pima sandy loam contains a very low amount of available native phosphorus.

The affect of rates of application on the availability of the algal phosphorus is shown in Table 5. An increase in the rate of application was associated with an increase in rate of absorption. The percentage uptake, however, was not proportional to the increase in rate of application. For instance, the phosphorus in rye grass absorbed from algae added at a rate of 50 lbs. P_2O_5/A at the time of the first cutting amounted to about 22 percent. The absorption amounted to only 27 percent when the same material was applied at double this rate.

The Availability of the Phosphorus of Mature Barley Residues

The availability of phosphorus to rye grass from mature barley straw and root residues varies in the various soils in the same manner

TABLE 6. THE ABSORPTION OF PHOSPHORUS FROM ALGAE BY RYE GRASS GROWN IN MOHAVE CLAY LOAM AND QUARTZ SAND*

		PIMA SANDY LOAM					QUARTZ SAND				
PLANT AGE	TIME AFTER APPLICATION	yield	total phosphorus		phosphorus from algae		yield	total phosphorus		phosphorus from algae	
					First Cutting						
days	days	gms/pot	percent	mgm.	percent	mgm.	gms/pot	percent	mgm.	percent	mgm.
22	1	0.68	0.23	1.6	5	0.1	1.63	0.18	2.9	25	0.7
25	3	0.70	0.23	1.6	20	0.3	1.63	0.23	3.7	26	1.0
28	7	1.12	0.25	2.8	39	1.4	2.09	0.20	4.1	50	2.1
35	14	1.36	0.23	3.1	47	1.5	3.14	0.14	4.3	60	2.6
42	21	1.55	0.20	3.1	59	1.8	3.96	0.11	4.3	60	2.6
49	28	1.78	0.17	3.0	53	1.6	3.98	0.09	3.5	59	2.0
56	35	3.13	0.14	4.3	53	2.1	5.22	0.06	3.2	53	1.7
63	42	3.82	0.11	4.4	51	2.2	5.82	0.06	3.6	49	1.8
70	49	4.64	0.10	4.6	51	2.4	--**	--	--	--	--
					Second Cutting						
63	42	2.84	0.11	3.1	62	1.9	3.39	0.07	2.4	89	2.1
65	44	2.61	0.10	2.6	67	1.8	2.96	0.09	2.5	90	2.2
69	48	2.40	0.10	2.5	77	1.9	3.28	0.07	2.3	85	2.0
76	55	2.26	0.05	1.8	58	1.0	2.20	0.06	1.2	77	0.9
83	62	2.34	0.08	1.8	55	1.0	2.29	0.05	1.5	72	1.1
90	69	2.53	0.07	1.8	49	0.9	2.10	0.06	1.3	73	1.0

* 9.934 mgm. of phosphorus added per pot of 1 Kg. soil or sand. The above figures are calculated on the basis of oven dry material.

** No treatment made

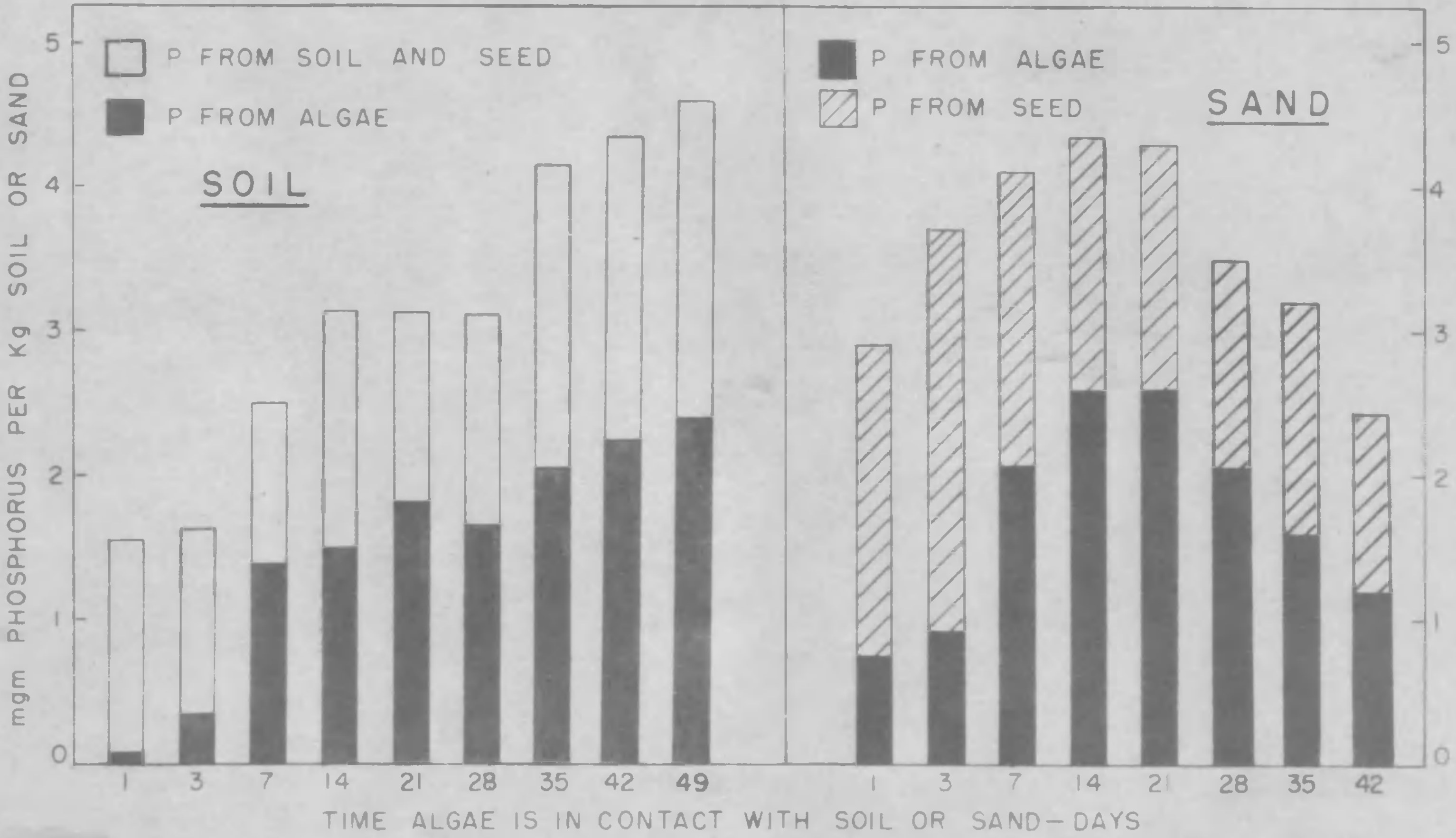

FIG. I RATE OF PHOSPHORUS UPTAKE FROM ALGAL TISSUE IN MOHAVE CLAY LOAM AND SILICA SAND (ALGAE ADDED AT RATE OF 50 LBS P_2O_5/ACRE)

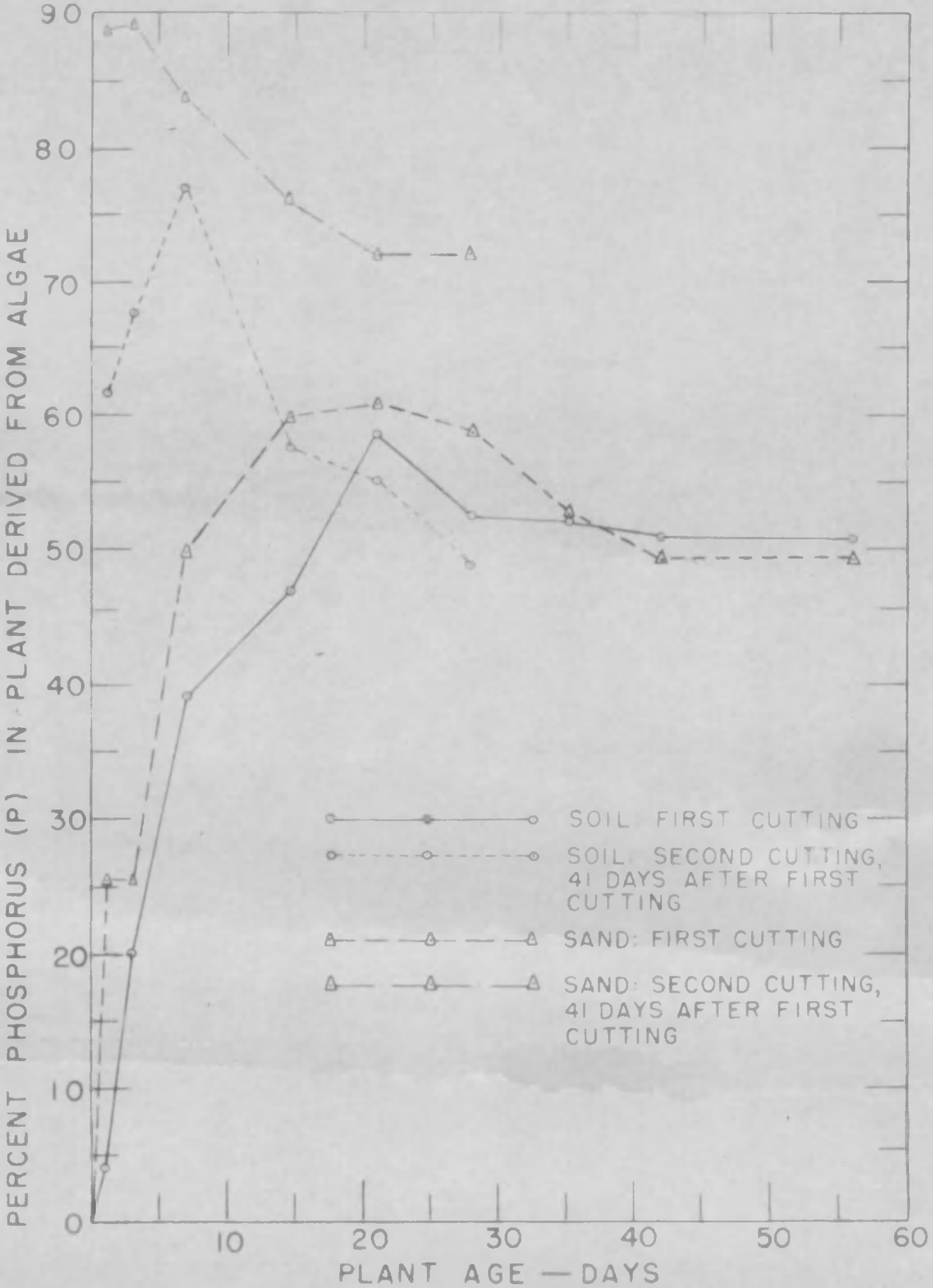

FIG. 2 PERCENTAGE PHOSPHORUS IN RYE GRASS DERIVED FROM ALGAE ADDED TO MOHAVE CLAY LOAM

as that of fungal and algal residues (Table 5). The percent of phosphorus derived from barley residues by rye grass grown in Pima sandy loam, Mohave clay loam, and Pima clay loam decreases in the order of the soils given.

The absorption of phosphorus by rye grass from the barley residues was markedly influenced by the rate of application. Barley residues added at a rate of 100 lbs. P_2O_5/A furnished more than twice as much phosphorus to the rye grass as that added at the 50-pound rate. Moreover, the 150-pound rate furnished more than three times the amount of phosphorus as did the 50-pound rate.

The percentage phosphorus in the rye grass derived from barley residues was not the same at the different sampling dates for a single soil. Materials added at the rate of 50 lbs. P_2O_5/A yielded more phosphorus to the grass at the time represented by the first and third than the second cutting. At higher rates of application, however, the availability of the phosphorus appeared to increase directly with the time of contact with the soil.

In general, barley straw furnished slightly more phosphorus to the rye grass than did barley roots.

The Availability of Phosphorus from Grain Crop Residues

The absorption of phosphorus from the various grain crop residues (barley, flax, hegari, and wheat) added to Mohave and Pima clay loam by rye grass is shown in Tables 7 and 8. The availability of the phosphorus of these residues was very low in both soils. Moreover, absorption from the various residues in a single soil was practically the

TABLE 7. THE UTILIZATION OF PHOSPHORUS OF GRAIN CROP RESIDUES BY RYE GRASS FROM MOHAVE CLAY LOAM

CROP RESIDUE	P_2O_5 ADDED IN RESIDUE	YIELD*	TOTAL P IN RYE GRASS		P IN GRASS DERIVED FROM RESIDUE	TOTAL P ABSORBED FROM RESIDUE
	lbs./A	gms.	percent	mgm.	percent	percent
Barley straw 1a	100	1.63	0.09	1.4	9	0.6
Barley straw 2a	100	1.90	0.08	1.6	8	0.6
Barley straw 3a	100	1.70	0.08	1.6	4	0.3
Barley straw 4a	100	1.30	0.09	1.1	8	0.4
Barley straw 5a	100	1.10	0.09	1.0	2	0.1
Barley straw 2a	50	1.34	0.11	1.5	4	0.6
Barley roots 1a	100	3.23	0.13	4.1	17	3.4
Barley roots 3a	100	3.02	0.11	3.4	10	1.7
Barley roots 4a	100	2.07	0.12	2.4	11	1.3
Barley roots 5a	100	2.25	0.13	2.9	8	1.2
Barley roots 2a	50	2.37	0.12	3.0	7	2.0
Flax straw	100	1.39	0.08	1.2	4	0.2
Flax straw	25	2.41	0.16	3.9	6	4.7
Flax roots	25	2.55	0.12	3.0	3	1.7
Hegari stalks	50	1.83	0.07	1.3	1	trace
Hegari roots	50	2.40	0.11	2.6	3	0.6
Wheat straw	100	1.22	0.09	1.0	3	0.1
Wheat straw	50	1.45	0.09	1.3	1	trace
Wheat roots	50	3.10	0.13	4.2	3	0.1

*Average of 2 pots; 1 Kg. of soil/pot; based on oven-dry material; one cutting

TABLE 8. THE UTILIZATION OF PHOSPHORUS OF GRAIN CROP RESIDUES BY RYE GRASS FROM PIMA CLAY LOAM

CROP RESIDUE	P_2O_5 ADDED IN RESIDUE	YIELD**	TOTAL P IN RYE GRASS		P IN GRASS DERIVED FROM RESIDUE	TOTAL P ABSORBED FROM RESIDUE
	lbs./A	gms.	percent	mgm.	percent	percent
Barley straw 1a	100	5.42	0.34	18.5	14	13
Barley straw 2a	100	4.81	0.34	19.5	13	13
Barley straw 3a	100	3.60	0.37	13.3	12	8
Barley straw 4a	100	3.70	0.28	10.4	10	5
Barley straw 5a	100	2.06	0.47	9.5	13	6
Barley straw 2a	50	5.94	0.33	19.5	7	14
Barley roots 1a	100	6.66	0.29	19.5	12	12
Barley roots 2a	--*	--	--	--	--	--
Barley roots 3a	--*	--	--	--	--	--
Barley roots 4a	100	6.18	0.28	17.7	12	11
Barley roots 5a	100	6.89	0.27	18.4	12	11
Flax straw	--*	--	--	--	--	--
Flax roots	--*	--	--	--	--	--
Hegari stalks	50	6.22	0.24	14.4	6	9
Hegari roots	50	6.91	0.33	22.5	5	10
Wheat straw	100	5.85	0.37	21.6	10	11
Wheat straw	50*	--*	--	--	--	--
Wheat roots	--*	--	--	--	--	--

*No treatments made
**Average of 2 pots; 1 Kg. of soil/pot; based on oven-dry material; one cutting

same except for hegari. The phosphorus of hegari stalks appeared to be less available than that of straw from other crops.

The rye grass absorbed less phosphorus, both on a basis of percentage in the plant and total in the crop, from Mohave than Pima clay loam. Upon cursury examination this may appear to be a reversal of the situation reported earlier in the manuscript in Table 5. The crop materials used in this experiment, however, were so low in phosphorus that when placed in a soil of very low available soil phosphorus as the Mohave, the soil organisms mobilized all the available phosphorus for decomposition. This left little or no phosphorus for the rye grass. The absorption of phosphorus from the residues in a soil abundantly supplied with available phosphorus as the Pima clay loam was about as expected judging from previous data.

In nearly all cases, the roots added to the Mohave soil furnished more phosphorus to the rye grass than the straw. The poorer rate of decomposition of the roots may have been a factor in the demand by the organisms for threshold quantities of available phosphorus.

The Availability of Phosphorus from Legume Crop Residues

The absorption of phosphorus from alfalfa and clover hay by rye grass was about the same from a single soil (Table 9). Less phosphorus was absorbed by rye grass from the alfalfa hay incorporated in Mohave than from Pima soil. The percentage phosphorus derived from alfalfa hay by the grass was 5 and 9 for the respective soils. Mature alfalfa yielded no more phosphorus to rye grass than barley straw applied at the same rate. Alfalfa roots supplied slightly more phosphorus to

TABLE 9. THE UTILIZATION OF PHOSPHORUS OF LEGUME CROP RESIDUES BY RYE GRASS FROM TWO SOILS

CROP RESIDUE	P_2O_5 ADDED IN RESIDUE	YIELD	TOTAL P IN RYE GRASS		P IN GRASS DERIVED FROM RESIDUE	TOTAL P ABSORBED FROM RESIDUE
			MOHAVE CLAY LOAM			
	lbs./A	gms.	percent	mgm.	percent	percent
Alfalfa hay	50	1.49	0.11	1.6	5	0.8
Clover hay	--*	--	--	--	--	--
Alfalfa roots	50	1.82	0.11	2.0	8	1.6
Clover roots	50	1.60	0.11	1.8	4	0.8
			PIMA CLAY LOAM			
Alfalfa hay	50	5.23	0.43	22.6	9	21
Clover hay	50	5.48	0.41	22.6	7	16
Alfalfa roots	--**	--	--	--	--	--
Clover roots	--**	--	--	--	--	--

*Sample contaminated

**No treatment made

Average of 2 pots; 1 Kg. of soil/pot; based on oven-dry material; one cutting the grass than the hay during the limited time of the experiment.

The Availability of Phosphorus from Vegetable Crop Residues

Lettuce leaves applied to Mohave clay loam supplied more phosphorus to rye grass than tomato tops (Table 10). The phosphorus of the two materials, however, was about equally available to the grass when mixed into Pima clay loam. The percentage phosphorus in rye grass derived from lettuce leaves was higher from Mohave than from Pima soil. The fact that the lettuce leaves had a higher content of phosphorus than all the other materials accounts for its favorable absorption in Mohave clay loam. The phosphorus content of the leaves (0.323 percent) is more nearly equal to that of other residues used in previous experiments where a similar relationship in absorption was found between these two soils.

The Absorption of Phosphorus from Tomato Residue as Influenced by Different Soils

Tomato tops containing radiophosphorus was applied to four soils, Mohave clay loam, Tucson sandy loam, Tubac sandy loam, and Pima clay loam, to study the effect of available soil phosphorus on absorption of phosphorus from a crop residue by a succeeding crop. Data in Table 11 show that the phosphorus in the rye grass derived from the tomato tops was 7, 22, 24, and 8 percent from the four soils in the order mentioned above. The CO_2-soluble phosphorus was found to be 0.4, 1.8, 3.2, and 8.8 ppm for Mohave, Tucson, Tubac, and Pima soil respectively. Mohave clay loam is considered to be very deficient in available

TABLE 10. THE UTILIZATION OF PHOSPHORUS OF VEGETABLE CROPS BY RYE GRASS FROM TWO SOILS

CROP RESIDUE	P_2O_5 ADDED IN RESIDUE	YIELD†	TOTAL P IN RYE GRASS		P IN GRASS DERIVED FROM RESIDUE	TOTAL P ABSORBED FROM RESIDUE
			MOHAVE CLAY LOAM			
	lbs./A	gms.	percent	mgm.	percent	percent
Lettuce leaves	50	1.74	0.11	2.0	14	1.9
Tomato tops	50	1.38	0.12	1.6	7	1.1
Tomato tops	100	1.80	0.11	2.0	11	1.1
Tomato roots	50	1.48	0.11	1.7	11	1.9
			PIMA CLAY LOAM			
Lettuce leaves	50	5.16	0.46	23.6	8	18
Tomato tops	50	5.85	0.37	21.9	8	19
Tomato tops	--*	--	--	--	--	--
Tomato roots	--**	--	--	--	--	--

*No treatment made with tomato tops at 100 lbs. P_2O_5/A

**No treatment made

† Average of 2 pots; 1 Kg. of soil/pot; based on oven-dry material; one cutting

TABLE 11. THE UTILIZATION OF THE PHOSPHORUS OF TOMATO TOPS BY RYE GRASS AS INFLUENCED BY DIFFERENT SOILS*

SOIL	CO_2-SOLUBLE PHOSPHORUS (P)	YIELD†	TOTAL P IN RYE GRASS		P IN GRASS ABSORBED FROM RESIDUE	TOTAL P ABSORBED FROM RESIDUE
	ppm	gms.	percent	mgm.	percent	percent
Mohave clay loam	0.4	1.38	0.11	1.6	7	1.1
Tucson sandy loam	1.8	2.33	0.17	3.9	22	8.7
Tubac sandy loam	3.2	2.14	0.15	3.2	24	7.7
Pima clay loam	8.8	4.94	0.44	21.9	8	18.6

*Tomato tops were added at the rate of 50 lbs. P_2O_5/A

†Average of 2 pots; 1 Kg. of soil/pot; based on oven-dry material; one cutting

phosphorus by standards originating at the Arizona Agricultural Experiment Station whereas Pima clay loam is considered to be abundantly supplied. The Tubac and Tucson soils are moderatly low in available phosphorus.

The Absorption of Phosphorus from Phosphoric Acid in the Presence of Oat Straw

In order to study the effect of carbonaceous residues of various C/P ratio on the absorption of phosphorus by a crop, oat straw with and without H_3PO_4 was added to Mohave and Pima clay loam. Different proportions of oat straw and H_3PO_4 were added to the soils to provide a variation in the C/P ratio of the additions. The data in Table 12 show that the phosphorus-poor Mohave soil supported rye grass that absorbed the liquid H_3PO_4 to a greater extent than the phosphorus-rich Pima soil. The data are nearly identical with those published previously from this laboratory. Apparently the H_3PO_4 and oat straw were not sufficiently mixed or associated intimatly enough with each other to bring about changes in the absorption rates as indicated by the calculated C/P ratios. However, the data do show that widening of the C/P ratio by addition of carbonaceous material as oat straw to a soil depresses the absorption of soluble phosphate by a crop. Yields of rye grass were also temporarily depressed by applications of oat straw low in phosphorus (Table 12).

Addition of oat straw without H_3PO_4 depressed the grass yield as well as the amount of phosphorus absorbed by the grass compared with the yield and absorption from the check soils.

TABLE 12. THE UTILIZATION OF THE PHOSPHORUS OF H_3PO_4 BY RYE GRASS AS INFLUENCED BY ADDITION OF OAT STRAW

P_2O_5 ADDED AS H_3PO_4	OAT STRAW ADDED	C/P RATIO	YIELD	TOTAL P IN RYE GRASS		P IN GRASS ABSORBED FROM RESIDUE	TOTAL P ABSORBED FROM RESIDUE
			MOHAVE CLAY LOAM				
lbs./A	T/A		gm.	percent	mgm.	percent	percent
50	0	---	2.81	0.23	6.3	37	24
50	5	200	1.37	0.24	3.3	29	10
100	0	---	2.64	0.34	9.1	57	26
100	5	100	1.30	0.31	4.0	51	10
100	10	200	1.28	0.35	4.5	39	9
100	15	300	1.10	0.37	4.1	41	8
0	0	---	2.77	0.16	4.5	--	--
0	5	2075	1.00	0.10	1.0	--	--
0	10	2075	1.16	0.09	1.0	--	--
0	15	2075	0.73	0.10	0.7	--	--
			PIMA CLAY LOAM				
50	0	---	6.69	0.49	32.8	7	23
50	5	200	5.18	0.49	25.2	8	20
100	0	---	6.46	0.47	30.6	14	22
100	5	100	5.43	0.45	24.2	--*	--*
100	10	200	3.30	0.54	17.8	15	13
100	15	300	1.83	0.77	14.1	1	0.7
0	0	---	7.35	0.34	25.3	--	--
0	5	2075	4.87	0.48	23.4	--	--
0	10	2075	3.67	0.43	15.7	--	--
0	15	2075	2.39	0.56	13.4	--	--

*Sample lost before counted

Average of 2 pots; 1 Kg. of soil/pot; based on oven-dry material; one cutting

Total absorption of phosphorus of H_3PO_4 by the rye grass and yield of grass was greatest in the soils when no oat straw was applied. The rye grass from Mohave clay loam receiving 100 lbs. P_2O_5/A in the form of H_3PO_4 yielded dry material having about 57 percent of its phosphorus derived from the inorganic source. Only about 14 percent of the phosphorus of the grass from Pima clay loam was derived from the added H_3PO_4. Because of greater yield of plant material from the Pima soil, however, total absorption of added phosphorus was greater from this soil than from Mohave clay loam.

The Utilization of Phosphorus by Rye Grass as Influenced by Different Phosphorus Levels in the Plant Residues

The effect of different phosphorus levels in barley straw on phosphorus uptake is shown in Table 13. The percentage of the phosphorus in the rye grass derived from the added residues was considerably more from the Mohave clay loam than from the Pima soil. The percentage phosphorus in the rye grass derived from the straws of various phosphorus content was directly proportional to the amount found in the residue. In other words, less phosphorus was absorbed from materials of low phosphorus than of high phosphorus.

Yields of the rye grass on a single soil were very uniform. The yields of rye grass on Pima clay loam, however, were higher than those on Mohave clay loam. Results show that the total phosphorus uptake on the Pima soil was several times that on the Mohave soil. The total absorption was less from straws relatively low in phosphorus than from those high in phosphorus.

TABLE 13. THE PERCENTAGE PHOSPHORUS (P) IN RYE GRASS FROM BARLEY STRAWS OF DIFFERENT PHOSPHORUS CONTENT

MATURE BARLEY STRAW	PHOSPHORUS IN STRAW	TOTAL PHOSPHORUS ABSORBED BY RYE GRASS	PHOSPHORUS IN RYE GRASS FROM BARLEY STRAW	TOTAL PHOSPHORUS ABSORBED FROM BARLEY STRAW	PHOSPHORUS OF BARLEY STRAW ABSORBED BY RYE
MOHAVE CLAY LOAM					
	percent	mgm./pot*	percent	mgm.	percent
Straw 1	0.575	6.32	30	1.9	5
Straw 2	0.421	6.12	32	2.0	6
Straw 3	0.401	4.30	26	1.1	3
Straw 4	0.395	4.07	23	0.9	3
Straw 5	0.237	3.21	18	0.6	2
Straw 6	0.186	2.07	17	0.3	1
PIMA CLAY LOAM					
Straw 1	0.575	29.00	19	5.6	16
Straw 2	0.421	27.32	15	4.0	11
Straw 3	0.401	26.18	13	3.4	10
Straw 4	0.395	25.98	13	3.3	9
Straw 5	0.237	24.75	10	2.4	7
Straw 6	0.186	18.58	9	1.7	5

*Each pot contained 2 kilograms of soil; average of two pots; one cutting. 34.9 mgm. of phosphorus in plant material added per pot.

The Affect of the Rate of Decomposition of Crop Residues on the Availability of Phosphorus from Those Residues

Decomposition rate of crop residues in Mohave clay loam was measured in an attempt to determine the correlation between rate of decomposition and percentage phosphorus taken up from the residues. The results are given in Figures 3-8. The decomposition of eleven crop tops was consistantly more rapid than their corresponding roots except in the case of wheat (Fig. 8). Table 7 shows, in general, that the percentage phosphorus uptake from the residue varies inversely with the rate of decomposition. This is true, however, only on the Mohave clay loam, a soil containing very low available phosphorus, and for materials of relatively low phosphorus content (compare Tables 5, 7 and 8). The rapid decomposition of the residues was shown to increase the amount of phosphorus immobilized. Thus the rate of decomposition is an important factor in residues of low phosphorus content.

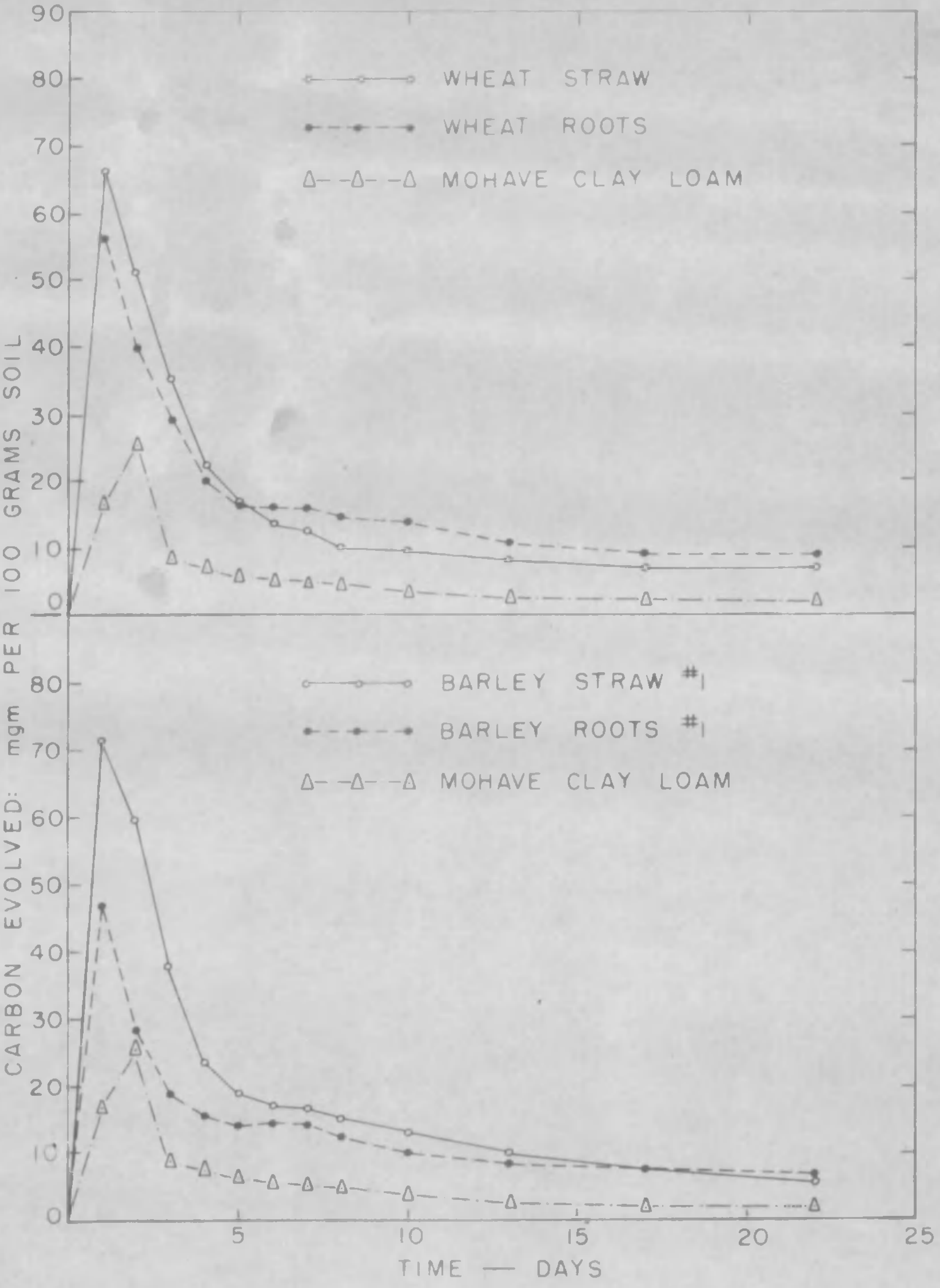

FIG. 3 DECOMPOSITION RATE OF PLANT RESIDUES IN MOHAVE CLAY LOAM. (1 gram MATERIAL PER 100 grams SOIL)

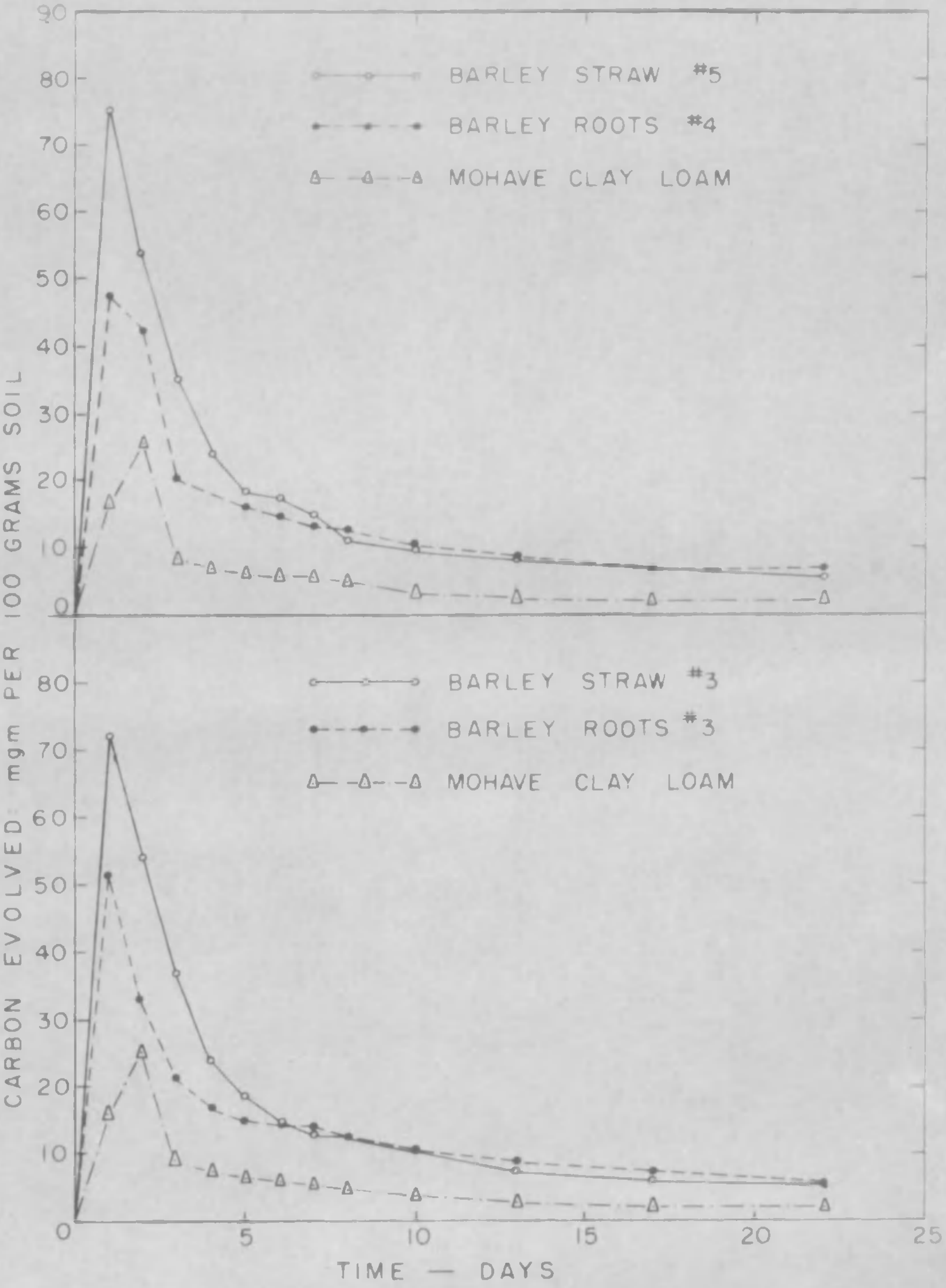

FIG. 4 DECOMPOSITION RATE OF PLANT RESIDUES IN MOHAVE CLAY LOAM (1 gram MATERIAL PER 100 grams SOIL)

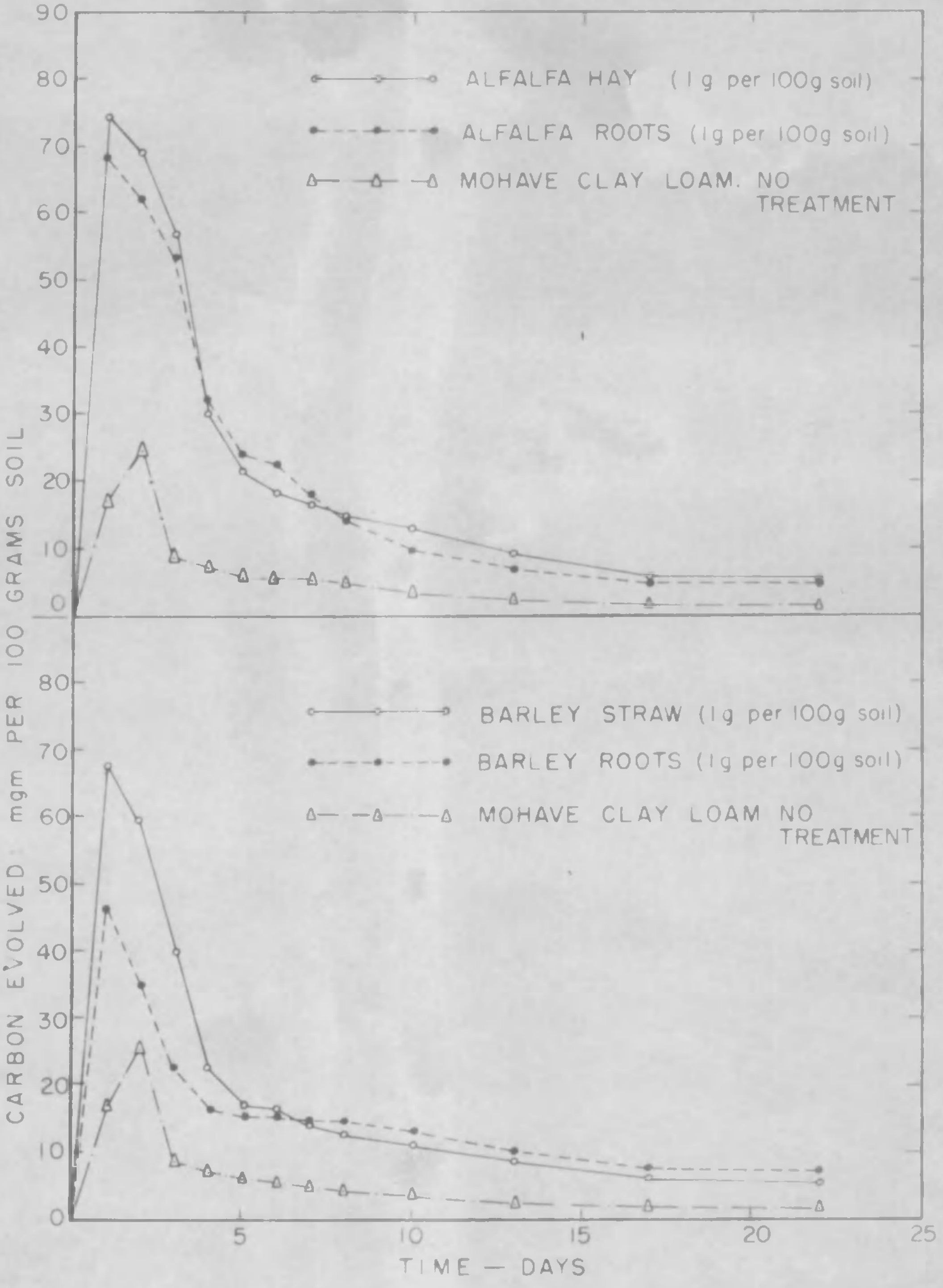

FIG. 5 DECOMPOSITION RATE OF PLANT RESIDUES IN MOHAVE CLAY LOAM (1 gram MATERIAL PER 100 grams SOIL)

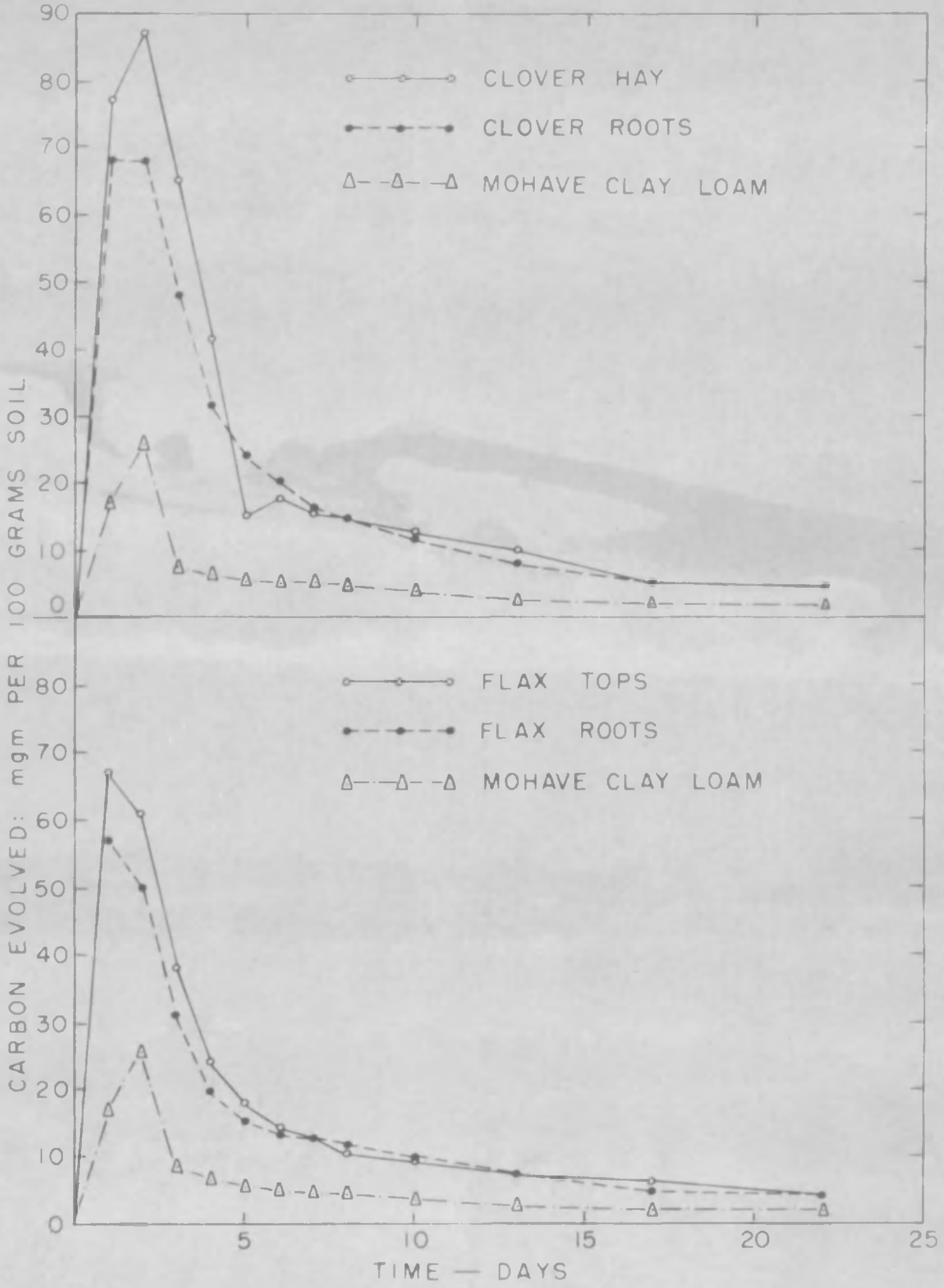

FIG. 6 DECOMPOSITION RATE OF PLANT RESIDUES IN MOHAVE CLAY LOAM (1 gram MATERIAL PER 100 grams SOIL)

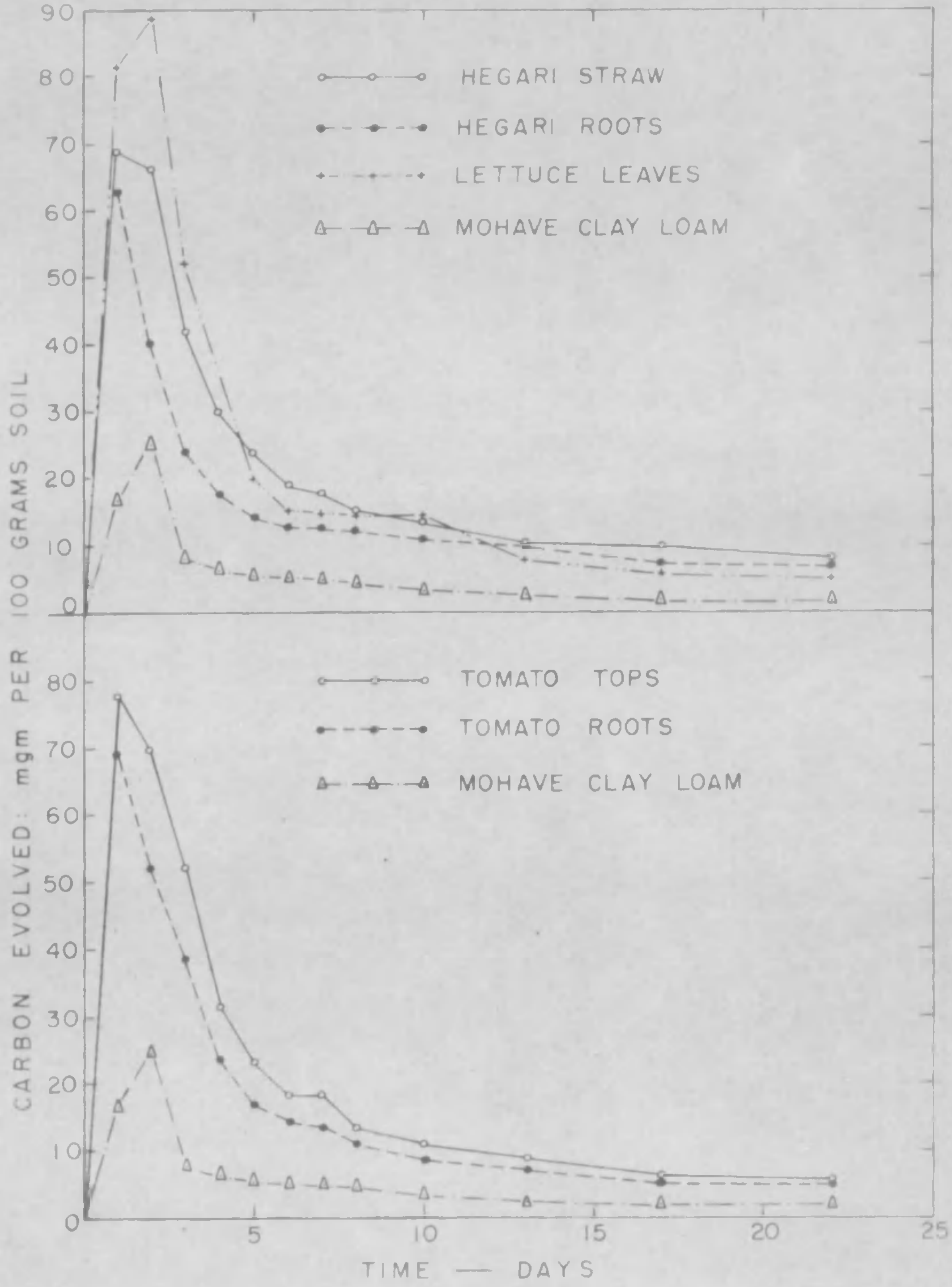

FIG. 7 DECOMPOSITION RATE OF PLANT RESIDUES IN MOHAVE CLAY LOAM (1 gram MATERIAL PER 100 grams SOIL)

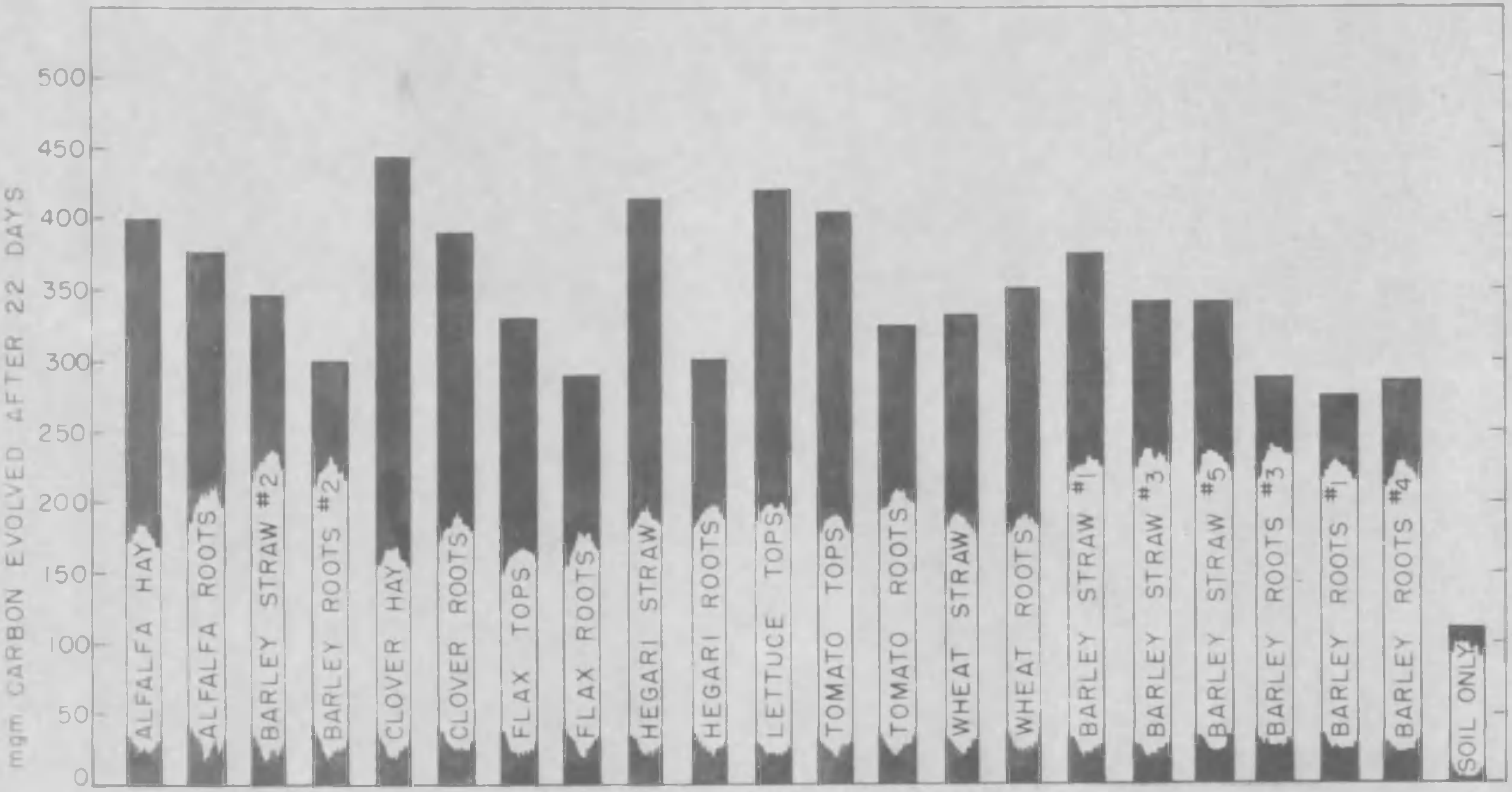

FIG. 8 TOTAL CARBON (IN MILLIGRAMS) EVOLVED IN THE FIRST 22 DAYS FROM MOHAVE CLAY LOAM WITH 1 GRAM TREATMENTS OF VARIOUS PLANT RESIDUES PER 100 GRAMS OF SOIL

DISCUSSION

It might be expected that the availability of the phosphorus of various biological materials would vary with the nature of the material. It does not appear logical, for instance, that the phosphorus of high-cellulose residues such as grain straws would be as available as phosphorus from the more proteinacious microbial cells which are easily and rapidily decomposed. An inorganic source of phosphorus such as H_3PO_4 would also be expected to be more available than the phosphorus of biological materials.

To verify these expectations, and to determine their extent, a study was made on various microbial and crop residues. Samples of the residues, which contained radioactive phosphorus, were thoroughly mixed into soil and planted to rye grass. The percentage of the phosphorus in the grass derived from the residues was used as the measure of the availability of the phosphorus in that residue. It should be noted, however, that the measurement of the availability of phosphorus from the residues was based upon the phosphorus uptake over a period of weeks. This time period permitted the decomposition of a large part of the incorporated biological materials, the fixation of mineralized phosphate and the continuous uptake of any small quantities of available phosphorus from the different sources present.

The phosphorus available at any one time depends upon several factors. Microbial or chemical fixation of the phosphorus occurs to a large extent. Whether or not the mineralized phosphorus from the residues is fixed in either way is, to some extent, dependent upon the available phosphorus already present in the soil. The extent of microbial fixation is a function of time and if the experiment is continued long enough, the reduced decomposition rate of the residue results in a large decrease in microbial population. These dead microorganisms will then release their phosphorus to be fixed again in some manner or to be absorbed by the plant.

With these considerations, the availability of the phosphorus from microbial or crop residues and from a soluble inorganic source might be nearly the same on a single soil provided the experiment continues long enough. This was found to be true on Mohave clay loam with comparisons made on algae, fungi, H_3PO_4 and barley. In this study, it was shown that the phosphorus of the microbial materials (fungi and algae) was very available to rye grass. In some instances on Mohave clay loam, the rye grass derived as much as 50-60 percent of its phosphorus from these added materials. Experiments with barley straw having a high percentage phosphorus (0.48 percent) showed that the phosphorus of barley straws was only slightly less available to rye grass than the phosphorus of microbial materials. This is also in agreement with other work done in this laboratory. Slight deviations may possibly be accredited to differences in phosphorus content of the different materials. This and other factors are discussed later.

Comparisons of an inorganic, soluble form of phosphorus, H_3PO_4, with algae showed the phosphorus of algae to be about as available to rye grass as the phosphorus of H_3PO_4 when applied to soils at the same rate. It is probable that many soils will not produce these same results. Other results obtained in this laboratory have shown that in some instances the availability of the phosphorus from algae and H_3PO_4 are not the same after prolonged periods of contact in the soil.

The low percentage phosphorus uptake (5-15 percent) obtained from the grain, legume, and vegatable crops (Tables 7-10) may appear to be in contradiction with the above findings on phosphate availability. However, temporary microbial fixation of the phosphorus from the residue is believed to be responsible for the lower absorption of residue-phosphorus from the phosphorus-poor Mohave than the phosphorus-rich Pima soil. A threshold value appears to have been established in the Mohave soil below which phosphorus could be made available to plants. In such instances when residues very low in phosphorus are added to soils deficient in phosphorus, microorganisms demand the available phosphorus from both sources to carry on decomposition. Thus when the crop residues low in phosphorus were added to Mohave clay loam, plant growth was seriously retarded due to the lack of this element.

Soil microorganisms will release phosphorus only after their requirements are satisfied. That such a threshold value for mineralization was not reached is evidenced by the fact that other straws (Tables 5 and 13) and lettuce (Table 9), which had a rather high concentration of phosphorus, supplied the rye grass growing on Mohave clay loam with an abundance of phosphorus. It would appear that in this instance the demand by the microorganisms was more than met and mineralization or release of phosphorus from the residues permitted the establishment of a supply of phosphorus available to the plants. The result was a relatively high uptake of phosphorus by rye grass from the lettuce and straws high in phosphorus from the Mohave clay loam.

The effect of adding hegari stalks (0.08 percent phosphorus), for instance, compared with the effect of adding lettuce leaves (0.32 percent phosphorus) to soils low in available phosphorus may be quite different. The economics of these findings are very important from a standpoint of successful crop production. Incorporation of crop residues low in phosphorus into soils also low in available phosphorus should be accompanied by additions of a supplemental source of phosphorus such as super-phosphate, liquid phosphoric acid or ammonium phosphate. On the other hand, it was found that additions of residues low in phosphorus to phosphate-rich soils has little influence on the phosphate status of the growing crop.

The influence of adding a residue high in phosphorus on the phosphorus status of a crop was well pointed out with mature barley straws. For example, a three-fold increase in phosphorus percentage of the straw resulted in about a five-fold increase in phosphorus absorbed from that straw (Table 13). There was an increase in both growth of the grass and of the percentage phosphorus of the rye grass derived from the residue.

It therefore appears desireable to determine for each crop some approximate C/P ratio which is considered to be "normal" or average for that particular crop in the field. These percentages would then serve as "reference" points for crop comparisons and also act as a basis for phosphate fertilizer recommendations. Without such a basis careful consideration of the C/P ratio of each residue will be required. This may prove to be tedious, time consuming and expensive.

Indications of the importance of the overall C/P ratio in the soil-residue mixture were obtained on the Pima clay loam (Tables 7-10). The pots treated with material having a high C/P ratio furnished nearly as much phosphorus as pots containing material having a low C/P ratio. This indicates that on Pima clay loam, a soil rich in CO_2-soluble phosphorus, the total phosphorus added is usually more important than the C/P ratio of the added material. This was not the case with Mohave clay loam. The C/P ratio of the material added seemed to determine the percentage phosphorus uptake from the residue.

The effect of the C/P ratio of the added material was tested to some extent with synthetically-made ratios. Oat straw and radioactive H_3PO_4 were mixed in soil in various proportions. In general, the yield and total phosphorus uptake of rye grass varied inversely with the C/P ratio of the material added. In general, the higher the percentage phosphorus, the higher the yield and total phosphorus taken up. It is realized that the C/P ratios of H_3PO_4-straw mixtures are not necessarily characteristic of crop residues. The form and combinations in which the phosphorus exists may be different in the two conditions. The intimacy and extent of root contact with the H_3PO_4 and the oat straw may possibly be quite different even in treatments that are otherwise identical. Possibly composting the H_3PO_4 and oat straw together before incorporating them into the soil would make them representative of crop residues.

Another consideration in the phosphorus absorption is the time in contact with the soil. The process of decomposition is not immediate and may take several weeks or months to complete even when under the most favorable conditions. Time must be given for mineralization of the phosphorus in the residue and in turn for that phosphorus immobilized by microbial activity to be released. Therefore, the five weeks allowed for most of these experiments probably do not give a complete picture of the phosphorus available over an extended period.

Further research on the evaluation of crop residues as a source of phosphorus for a succeeding crop is greatly needed. The C/P ratios of crop residues and their effects on the phosphorus threshold of the soil is also worthy of further study. Methods of application of the residues should be varied, and a much larger selection of soils should be used which vary in pH, texture, fertility and other natural differences. Additions of slightly soluble phosphorus compounds may be made to the soil to increase its CO_2-soluble phosphorus. By this method, the effect of an increase in available soil phosphorus on the uptake of phosphorus from crop residues could be studied. The possibilities for practical research on this subject are many. The large quantities of crop residues produced each year makes their evaluation highly practical and of economic importance.

SUMMARY

1. The utilization of phosphorus of various biological materials, fungi, algae, barley, hegari, wheat, flax, tomato, lettuce, alfalfa and clover by rye grass when added to three soils, Mohave and Pima clay loam and Pima sandy loam was studied under greenhouse conditions. In addition, detailed experiments were designed in the greenhouse to determine the influence of such factors as C/P ratio of a residue, and the microbiological decomposition rate of the residue on absorption of the phosphorus by rye grass.

2. The absorption of phosphorus from fungal material and algal cells by rye grass growing in two soils, Mohave and Pima clay loam, was found to be about the same. One of the species of fungi (_A. niger_) however, appeared to release phosphorus for use by rye grass to a lesser extent than the others.

3. The phosphorus of mature barley straw and roots was utilized by rye grass to a lesser extent than that of the fungal and algal material.

4. The phosphorus-poor Mohave clay loam supplied less native phosphorus to rye grass than the phosphorus-rich Pima clay loam, consequently more phosphorus from the residues was found in the grass from the Mohave than the Pima soil.

5. The phosphorus of algal cells in a phosphorus-poor soil, Pima sandy loam, was as available to rye grass within one week as algal cells in silica sand.

6. The percentage phosphorus derived by rye grass from various crop residues low in phosphorus was directly proportional to the phosphorus concentration of the residue. The percentage uptake was less on Mohave soil than on Pima clay loam. Lettuce leaves, however, had a relatively high phosphorus content and furnished a larger percentage phosphorus to rye grass on Mohave clay loam than on Pima clay loam.

7. The total phosphorus taken from the different crop residues was directly proportional to the availability phosphorus in the soil.

8. Oat straw having a C/P ratio of 2,075 was added to Mohave clay loam and Pima clay loam at various rates with and without H_3PO_4. Increasing the C/P ratio of the straw-H_3PO_4 addition decreased the uptake of phosphorus from H_3PO_4. Dry weights of rye grass were also measurably decreased at high C/P ratios. Additions of oat straw alone have similar but more pronounced affects to those just mentioned.

9. Decomposition rates conducted on crop materials of low phosphorus content show that the availability of phosphorus from residues having a low percentage phosphorus generally was inversely proportional to the decomposition rate of the residue.

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