CERTAIN FACTORS AFFECTING THE UPTAKE OF PHOSPHORUS, CALCIUM, AND STRONTIUM BY THREE TEST CROPS

by

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STATEMENT BY AUTHOR

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INTRODUCTION

The consumption of fertilizer in this country almost tripled during the period from 1939 to 1953. In most cases the farmer was benefited by the application of mineral fertilizers to his land; however, the greatest potential of plant nutrients are those native to the soil. Through a knowledge of the soil and the application of soil management practices that will conserve the nutrients in the soil in a form available to the plant, the farmer will receive the greatest return from his investment. A pound of soil may be leached with water as many as fifty times, yet the next leachate may contain measurable amounts of phosphorus and calcium--two critical elements in plant nutrition. Yet when a test crop is grown on the same soil before being leached, the crop may indicate a marked nutrient deficiency.

How can this large supply of native plant nutrients be made available for crop production? One way may be through the use of organic materials such as crop residues, which affect soil fertility by directly supplying plant nutrients to the crop as well as making the native plant nutrients in the soil more available. This latter point has been debated for some time, and there is a lack of experimental evidence to show that the indirect effect is of practical significance.
Experiments were designed to evaluate the indirect effect of crop residues on the availability of the native soil constituents. These experiments were primarily concerned with the effect of straw residues on the uptake of native soil phosphorus, calcium, and added strontium by a crop. The absorption of strontium added to the soil in the absence of straw residues was also studied.

**The Effect of Organic Matter on Phosphorus Availability to Plants**

With the aid of radiotracers and radiotracer techniques, some evidence has been obtained that crop residues applied to the soil make the native soil elements more available to the plant. Nielsen, Pratt, and Martin (33) reported evidence that tends to support this conclusion. They conducted a greenhouse experiment using corn as a test crop. One series of pots was treated with \( \text{KH}_2\text{PO}_4 \)

\(^1\), as the source of phosphorus; another series was treated with alfalfa containing an equivalent amount of radioactive phosphorus. They used three soils and four treatments on each type of soil consisting of alfalfa containing \( \text{P}^{32} \), \( \text{KH}_2\text{PO}_4 \), alfalfa containing \( \text{P}^{32} \) plus \( \text{KH}_2\text{PO}_4 \), and alfalfa plus \( \text{KH}_2\text{PO}_4 \) besides a check to which no nutrients were added to the soil. Except for the alfalfa and

\(^1\) \( \text{P}^* \) indicates radioactive form of the element.
KH₂P₄₀₄ treatment, the addition of alfalfa produced a higher total of phosphorus in the corn than when KH₂P₀₄ was the only source of fertilizer P. Furthermore, the total P in the corn was greater where alfalfa was the only source of fertilizer phosphorus than where only the soluble KH₂P₀₄ was used. They suggested that it was not the phosphorus in the alfalfa that was more available than that from the KH₂P₀₄ but that the decomposition products of alfalfa increased the availability of the residual phosphorus.

One of the factors that hinder plant growth in calcareous soils is the fixation of mineral phosphorus in a slowly available form by soil constituents. Yuen and Pollard (49) reported that the addition of organic matter reduces the capacity of soils to fix added phosphorus as determined by recovery of phosphorus by various extracting reagents. Stanford and Pierre (42), in a discussion of the fixation of applied phosphorus, mention Steel's work, who found that humic, oxalic, and citric acids were effective in reducing fixation of added phosphorus. Dalton (10) prepared cultures which included precipitated iron and aluminum phosphates. A crop was grown in these cultures and phosphate uptake determined. He concluded that organic matter made phosphate available from these cultures because of the ability of the metabolic products of microbial decomposition to form stable complex molecules with the iron and aluminum that are responsible for phosphate fixation in acid soil.
Fuller and Dean (15) showed that when green manures were applied to four acidic soils about 70 per cent as much phosphorus was absorbed by the succeeding crops as when superphosphate was applied on a basis of equivalent phosphorus. However, they also found that when the green manures were placed in a layer to simulate field applications, the percentage utilization of phosphorus was greater than that from superphosphate applied in a layer one inch below the surface of the soil on an equivalent phosphorus basis. In another greenhouse study using six calcareous soils, Fuller and Rogers (20) reported that young barley and medium mature barley supplied a greater proportion of phosphorus to rye grass than liquid phosphoric acid.

In view of the conflicting results obtained from studies on the influence of organic residues on the uptake of soil phosphorus, as well as its effect on total phosphorus uptake, additional information is needed to clarify this question.

Factors Influencing Phosphorus Uptake by Plants

Some of the factors which influence the rate and amount of phosphorus made available to the plant from the soil and from added plant materials are:

1. Supply of available nitrogen (18, 30)

2. pH value of the soil (2, 11, 44)
3. Soil moisture (23, 28, 46)
4. Microbial population (6, 7, 22)
5. Carbon:nitrogen ratio (5, 21)
6. Carbon:phosphorus ratio (3, 21)
7. Native soil availability (10, 20)

One of the most important of these factors is the role played by the soil microorganisms. The soil is a living system with a dynamic microbial population, mutually competitive and highly responsive to changes in its food supply. For this reason the use of green manures or crop residues has a marked effect upon the dynamic equilibrium of the soil. This effect may be either detrimental or advantageous to plant growth. The work done by Winogradsky, Beijerinck, Omeliansky, and others as described by Waksman (47) opened up rich fields of investigation on this question through the development of soil microbiology.

**Use of Radiotracers in Plant Studies**

One tool that has greatly aided in determining the effect of organic matter on the uptake of soil nutrients by plants is the radioisotope (45). Since the production of isotopes by the atomic pile method, it has been economically possible to use isotopes in many fields of research. Early in the use of isotopes in biological systems there was
a difference of opinion as to whether the use of radioisotopes in the
amounts normally used for experimentation were detrimental to the
metabolic processes of the plant (26, 36, 41). It is now generally
agreed that in low concentrations such as those used in this research,
there are no measurable adverse effects. Work done by Penner (36)
indicates that when radioactive phosphorus was used, no alteration in
the ratio of soil to fertilizer phosphorus occurred. This study is pri-
arily concerned with the ratio of soil to fertilizer phosphorus, as well
as the ratio of soil calcium to fertilizer calcium and strontium, and it
is assumed that the radioisotopes will not affect adversely the nutrient
absorption process in the plants used in these experiments.

There are two primary advantages in using tracer elements in
studying plant-nutrient relationships. It provides (a) a quantitative
method of tracing an element in a series of chemical reactions or within
a plant, and (b) a quantitative method for determining the uptake of a
specific element by a plant. The present investigation utilized the
latter method.

**Availability of Native Soil Calcium to Plants**

Very little work has been reported on the availability of native
soil calcium or the uptake of calcium as a result of addition of crop
residues to calcareous soils. Flocker and Fuller (12) found that the
amount of available calcium, as indicated by the amount absorbed by rye grass, was independent of the CaCO₃ content of the soil, although the latter ranged from 0 - 13 per cent. They also found, as did Fried and Dean (13), a highly significant correlation between the plant available calcium and the exchangeable calcium in the soils studied.

**Strontium Absorption by Plants**

Recently, considerable interest has developed over the uptake of strontium by plants due to the fact that Sr⁹⁰ is a product of the nuclear fission of uranium. Plants readily absorb strontium. Romney et al. (40), using soils varying in pH value from 5.7 - 8.6 and in exchangeable calcium from 0.4 - 12.4 meq./100 gm., showed that barley absorbed virtually no Y⁹¹, Ru¹⁰⁶, Cs¹³⁷, or Ce¹⁴⁴ from these soils, but Sr⁹⁰ was readily taken up. Strontium absorption from calcareous soils by a number of crop plants has been reported by Fuller and Flocker (16). Menzel (31) showed an inverse relationship to exist between the calcium-strontium ratio in cowpeas and the exchangeable calcium in the soil. He used soils with a widely varying exchangeable calcium content. Fuller and Flocker (16) demonstrated the same relationship between the exchangeable calcium content and uptake of strontium by plants.
The Strontium-Calcium "k" Value

It has been shown by a number of investigators (9, 25, 27) that plants do not differentiate between calcium and strontium when absorbing these nutrients from solutions or soil. Menzel and Heald (32) studied the competitive uptake by plants of potassium, rubidium, and cesium in addition to calcium, strontium, and barium. They showed that the uptake of calcium and strontium by the plant was proportional to their concentration in the nutrient solution and expressed it as follows:

\[
\frac{\text{Sr in plant}}{\text{Ca in plant}} = k \cdot \frac{\text{available Sr in soil}}{\text{available Ca in soil}}
\]

where \( k \) is the "distribution factor". According to Menzel and Heald (32), \( k \) is considered to be an index of similarity in behavior of two elements toward uptake by the plant; that is, it indicates the specific rate of entry or the percentage of these ions in the nutrient medium entering the plant in unit time. In their study with cowpeas and sunflowers grown in nutrient solutions under artificial light, strontium appeared to be absorbed to a slightly greater extent than calcium as indicated by a Sr/Ca ratio in the plant of 1.1 times that in the nutrient solution. They found, also, that the strontium was slightly more concentrated in the roots than in the other parts of the plant and that the Sr/Ca ratio became progressively lower in the stems, petioles, and leaves.
Menzel (31), in an earlier experiment, reported that the "distribution factor" for strontium and calcium in cowpeas grown in soil was 0.4. He suggested that the difference between this value and 1.1 may be due to an exchange of strontium and calcium between the soil and the solution. Redeske and Selders (38), using the Neubauer technique, showed that the amount of strontium absorbed by barley was proportional to the strontium in the nutrient solution up to 100 p.p.m. What effect might organic matter have on the uptake of strontium by a test crop?

Nishita et al. (34) observed, by the Neubauer technique, that the addition of organic matter depressed the uptake of Sr\(^{90}\) whereas in a later report (35) they showed that, using the pot culture method, the absorption of Sr\(^{90}\) and Ca by tomato plants was highest upon addition of 1-2 gm. of organic matter per 100 gm. of soil. In the presence of larger amounts of organic matter, the uptake of both Sr\(^{90}\) and Ca was depressed.

Sr\(^{89}\) was used in all studies reported in this thesis because the half life is only 53 days as compared with 19.9 years for Sr\(^{90}\). Using the short-lived radioactive strontium reduces the radiation hazard.

These investigations are particularly significant in light of the hazard of radioactivity in the effect on living cells. The answers to such questions as: How much of these nuclear fission products are concentrated in vital food crops and under what conditions are they absorbed?--In what way do these products enter into the biological and chemical
reactions in the soil?—How do plants respond in the presence of these fission products?—are vital to human existence in areas where fallout may occur.

**Objectives of the Study**

The main objective of the present investigation was to determine the uptake of native soil calcium and phosphorus and added strontium by plants as affected by straw residues. Several closely related phases of the problem were investigated. These were: (a) the effect of straw added to calcareous soils on the yield of a test crop, (b) the effect of straw on the "A" value of soil nutrients as determined by the test crop, (c) the uptake of radiostrontium from calcareous and noncalcareous soils by plants, and (d) to determine the "distribution ratio" of strontium to calcium in the plant.
EXPERIMENTAL METHODS

Preparation of labeled crop residues and labeled nutrients.

Barley was grown in steel trays to provide the straw for use in the experiment. Four rectangular trays, six by 24 by 48 inches, and one circular tray eight inches deep and 15 inches in diameter were used. Two inches of coarse gravel, one inch of fine gravel, and one inch of fine sand were placed in three of the rectangular trays. Four inches of fine sand were placed in the fourth tray used to grow barley containing irradiated calcium. Five inches of fine sand were placed in the circular tray and barley containing irradiated strontium was grown in this tray. The barley was planted in rows one-fourth inch deep and one and one-half inches apart.

Thirteen grams of irradiated $\text{KH}_2\text{PO}_4$ were dissolved in 500 ml. of distilled water. This solution was fed to the growing barley plants at a rate of 100 ml. per tray. The resulting barley contained 0.25 per cent phosphorus in the leaves and stems. Six and one-half grams of irradiated $\text{KH}_2\text{PO}_4$ were dissolved in 250 ml. of distilled water, and 50 ml. of this solution was fed to the barley in another tray, resulting in 0.09 per cent phosphorus in the leaves and stems. Nonradioactive
phosphorus was fed to the barley in the third tray, which resulted in straw having 0.68 per cent phosphorus.

The radiocalcium solution was prepared by dissolving 5 gm. of irradiated CaCO$_3$ in 500 ml. of a solution consisting of 10 ml. of glacial acetic acid and approximately 490 ml. of distilled water. One hundred ml. of this solution added to the barley produced straw containing 0.15 per cent irradiated calcium.

The radiostrontium solution was prepared by dissolving 1 gm. of irradiated Sr(NO$_3$)$_2$ in 250 ml. of distilled water. The barley was given 100 ml. of this solution to produce straw containing radioactive strontium.

The crop was fed by subirrigation with a nutrient solution devoid of the specific element where the radioactive isotope was to be substituted in the plant residues, i.e., where barley with irradiated phosphorus was grown, a nutrient solution containing no phosphorus was fed to the crop. All crops were subirrigated alternately with nutrient solution and distilled water to prevent excessive salt accumulation.

Two cuttings of the crops were made, one about 10 weeks after seeding and the second about five weeks after the first cutting. The residues, consisting of tops only, were washed with distilled water and dried at 65°C. to constant weight. The material was then ground to pass a 40-mesh screen, and subsequently analyzed for plant nutrients.
Pot culture procedure and treatments for the phosphorus, calcium, and strontium study.

**Phosphorus study** -- This experiment was conducted in the greenhouse in glazed pots containing 1 kg. of air-dried soil. The straw residues and irradiated phosphorus were thoroughly mixed with the soil at rates of 50 pounds and 100 pounds P per acre. Ammonium nitrate was added at the rate of 150 pounds N per acre. Additional nitrogen in the same form was added throughout the experiment when the crop appeared to be retarded in its growth due to nitrogen deficiency. Each treatment was replicated three times with the exception of those involving straw of low radioactive phosphorus content which were duplicated.

**Calcium study** -- The crop residue and the radioactive calcium were thoroughly rolled and mixed with the air-dried soil at rates of 2 meq. per kg. of soil. Nitrogen, at the rate of 150 pounds per acre in the form of NH₄NO₃, was added throughout the growth period of the crop. In a second calcium experiment, radioactive calcium and strontium were added in solution or as straw at the rate of 1 meq. per kg. of soil. Nitrogen was supplied at the rate of 150 pounds per acre as NH₄NO₃. In order to provide phosphorus, H₃PO₄ was added at the rate of 130 pounds P₂O₅ per acre and additional nitrogen at the rate of 75 pounds N per acre.

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2 Whenever reference is made to quantities per acre in this thesis, it refers to an acre of soil 6 2/3 inches deep.
pounds N per acre added throughout the period of growth of the crop as needed. The treatments were replicated three times, except when the straw was not available in the quantity required. In such instances duplicate treatments were applied. The soils were moistened with distilled water to about 60 per cent of field capacity and placed in glazed pots after which they were seeded to rye grass as the test crop. The crops were grown in the greenhouse, and the treatments completely randomized in a single block for each crop.

**Strontium study** -- Eight soils, four from Arizona varying in calcium carbonate and exchangeable calcium content and four from the humid area east of the Mississippi varying in exchangeable calcium, were used (Table 1). The crops, Henry wheat and Ranger alfalfa, were planted in #10 metal cans holding about 3 kg. of air-dried soil and grown under greenhouse conditions. To insure uniform mixing of the radiostrontium with the soil, a 1:1 soil suspension, consisting of 100 ml. of distilled water per 100 gm. of soil, was supplied with a solution of radiostrontium, as Sr(NO₃)₂, of about 2.5 microcurie activity. The suspension was allowed to dry, then water added, stirred and dried again. This process was repeated three times. After final drying of the soil so treated, it was pulverized and blended with the 2-3 kg. soil sample by the use of a twin shell mechanical mixer. To this mixture of soil and radiostrontium, phosphorus in the form of NH₄H₂PO₄ was added at the
rate of 100 pounds per acre and enough KNO₃ to supply 100 pounds per acre of nitrogen in each pot. Additional nitrogen and phosphorus were added as needed. Distilled water was added to bring the soil to about 75 per cent of the water-holding capacity. The pots were then seeded to wheat and alfalfa. "Orthocide-50"³ was added to prevent the growth of fungus at the soil surface. Each pot was covered until the seeds had germinated. The treatments were applied in triplicate. A fourth pot containing no radiostrontium was used as a check.

The specific activity of the plant ash was determined on cuttings of the crop as previously described. This value was subtracted from that of the straw containing radiostrontium, thus yielding values of the net specific activity of both test crops. Two cuttings of the crops were made, one about 60 days after seeding and the second about 60 days later. The pots were randomized on a bench in the center of the greenhouse and occasionally interchanged.

Chemical and physical analysis of plant materials and soils.

The total phosphorus content of the straw and that of the test crops was determined colorimetrically as molybdovanado-phosphoric acid (29).

³ Contains 50 per cent captan, N-trichloromethylmercapto-4-cyclohexene-1,2-dicarboximide, and 50 per cent inert ingredients. Produced by California Spray-Chemical Corporation, Richmond, Calif.
Total calcium and the calcium-plus-strontium content of the straw and of the test crop were determined by the Versenate method (8). Calcium was also determined by the D. U. Beckman flame photometer. All solutions were passed through a resin exchange column (1), using Dow 10X2 anion resin to remove phosphorus before determining the calcium in the solution.

The pH determinations were made on the soil paste with a Beckman pH meter.

Exchangeable calcium was determined by the ammonium acetate extraction procedure (4).

The radioactive elements in the crop were measured by ashing on aluminum planchets in gram quantities and counting directly in the gas chamber of a proportional counter. The Sr\(^{89}\) absorbed by the wheat and alfalfa was measured by a scalar counter\(^4\). Allowance was made for self-absorption when necessary. Standards were prepared by taking aliquots of the radioactive solutions used to feed the wheat and alfalfa, and the barley used to make straw residue and diluting to an activity of 1,000 to 10,000 counts per minute. This aliquot, consisting of 1 or 2 ml. of radioactive solution, was evaporated on an aluminum planchet over low heat and counted by the usual procedure. Counts with these

\(^4\) These instruments were manufactured by Nuclear Measurements Corp., Indianapolis, Ind.
standards were made at the time the activity of the ashed crop residue was determined.
EXPERIMENTAL MATERIALS

Soils

The soils used in these studies are partially characterized in Table 1. They had been selected on the basis of their calcium carbonate and exchangeable calcium contents and pH value.

Plant materials

Barley (*Hordeum vulgare* L., var. arivat) was used for straw in the phosphorus and calcium studies, only the tops being used. The phosphorus and calcium contents of the nonextracted straw are given under Preparation of labeled crop residues and labeled nutrients. Rye grass (*Lolium perenne* L.) was the test crop used in these studies.

The extracted straw used throughout the experiments was prepared by extracting plant nutrients from wheat straw with N NaOH and neutralizing with HCl. This resulted in a straw containing 0.01 per cent phosphorus and 0.10 per cent calcium.

Wheat (*Triticum vulgare* Vill., var. Henry) and alfalfa (*Medicago sativa* L., var. Ranger) were grown for the strontium study.
Table 1. Some chemical characteristics of the soils used.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Ex. Ca</th>
<th>Carbonate</th>
<th>CO$_2$</th>
<th>sol. P</th>
<th>pH value of paste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'meq./100 gm.'</td>
<td>%</td>
<td>p.p.m.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pima clay loam*</td>
<td>30.0</td>
<td>0.62</td>
<td>8.5</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Mohave clay loam*</td>
<td>15.4</td>
<td>0.03</td>
<td>T</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Elliot silt loam**</td>
<td>10.0</td>
<td>----</td>
<td>----</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>Fayette silt loam**</td>
<td>8.7</td>
<td>----</td>
<td>----</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>Laveen sandy loam*</td>
<td>8.6</td>
<td>4.14</td>
<td>1.8</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>Tucson sandy loam*</td>
<td>8.2</td>
<td>0.61</td>
<td>T</td>
<td>8.1</td>
<td></td>
</tr>
<tr>
<td>Crosby silt loam**</td>
<td>5.5</td>
<td>----</td>
<td>----</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Norfolk fine sandy loam**</td>
<td>2.0</td>
<td>----</td>
<td>----</td>
<td>6.1</td>
<td></td>
</tr>
</tbody>
</table>

* Calcium calculated by difference includes small amounts of Mg, Sr, and H.

** Calcium determined directly.
RESULTS

The Influence of Straw on the Availability of Native Soil Phosphorus to Rye Grass

Yield of test crop.

The application of straw to Mohave clay loam resulted in yields of rye grass greater than when mineral phosphorus in the form of KH$_2$PO$_4$ was added at an equivalent rate of P per acre (Figure 1). For example, straw containing two different levels of phosphorus, 0.25 per cent and 0.09 per cent, applied at equal rates of phosphorus to the Mohave soil, resulted in significantly higher yields of rye grass than applications of equivalent amounts of phosphorus as KH$_2$PO$_4$. Even the yields from the 50-pound phosphorus application as straw were significantly higher than the yield from the 100-pound application as KH$_2$PO$_4$. A higher yield of the test crop, however, was obtained on the soils fertilized with phosphorus than on the unfertilized soils.

The effect of straw residues, containing various amounts of phosphorus on yield of dry matter of the test crop, was similar when added to the Tucson sandy loam as when added to the Mohave soil, except with straw at the lowest level of phosphorus (Figure 1). Very
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dry Matter - Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MOHAVE CLAY LOAM</strong></td>
<td></td>
</tr>
<tr>
<td>Straw (0.25 % - P) 100 lb. P/A</td>
<td></td>
</tr>
<tr>
<td>Straw (0.09 % - P) 100 lb. P/A</td>
<td></td>
</tr>
<tr>
<td>Straw (0.25 % - P) 50 lb. P/A</td>
<td></td>
</tr>
<tr>
<td>Straw (0.09 % - P) 50 lb. P/A</td>
<td></td>
</tr>
<tr>
<td>Straw (0.68 % - P) 100 lb. P/A</td>
<td></td>
</tr>
<tr>
<td>KH₂PO₄ + Ex. Straw 100 lb. P/A</td>
<td></td>
</tr>
<tr>
<td>Ex. Straw</td>
<td>8.7 GMS.</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>100 lb. P/A</td>
</tr>
<tr>
<td>Check</td>
<td>None</td>
</tr>
</tbody>
</table>

| **TUCSON SANDY LOAM**           |                    |
| Straw (0.25 % - P) 100 lb. P/A   |                    |
| Straw (0.09 % - P) 100 lb. P/A   |                    |
| Straw (0.25 % - P) 50 lb. P/A    |                    |
| Straw (0.09 % - P) 50 lb. P/A    |                    |
| Straw (0.68 % - P) 100 lb. P/A   |                    |
| KH₂PO₄ + Ex. Straw 100 lb. P/A   |                    |
| Ex. Straw                       | 8.7 GMS.           |
| KH₂PO₄                          | 100 lb. P/A        |
| Check                           | None               |

**NOTE:**

- 1st. Cutting
- 2nd. Cutting

**FIG. 1 - THE INFLUENCE OF STRAW AND INORGANIC PHOSPHORUS ON THE YIELD OF RYE GRASS GROWN ON MOHAVE CLAY LOAM AND TUCSON SANDY LOAM.**
low yields of rye grass resulted upon the addition of barley straw containing 0.09 per cent phosphorus. There was no significant difference between the yield of rye grass treated with 100 pounds per acre of phosphorus as \( \text{KH}_2\text{PO}_4 \) on Tucson soil and that where no phosphorus was added. The discussion of these results is based on the sum of two cuttings of rye grass (see Table 2 for data on each cutting).

**Total phosphorus uptake by test crop.**

The total phosphorus uptake by rye grass from the Mohave clay loam was directly related to total yield (Figure 2 and Table 2). The highest uptake of phosphorus resulted from the addition of straw with 0.68 per cent \( P \). However, there was no significant difference in uptake between the \( \text{KH}_2\text{PO}_4 \) treatment and the treatment with straw containing 0.68 per cent phosphorus when equivalent amounts of \( P \) were used. In all treatments where phosphorus was added in the form of straw to Mohave clay loam, there was a significantly higher uptake of phosphorus by the test crop than on the soil where no phosphorus was added. This applied to the data based on the sum of two crops.

The total phosphorus uptake by rye grass from the Tucson sandy loam varied directly with yield of dry matter as it did in the Mohave soil. The highest uptake of phosphorus occurred where \( P \) as \( \text{KH}_2\text{PO}_4 \) and straw containing 0.68 per cent of phosphorus had been added to the
FIG. 2 - THE INFLUENCE OF STRAW AND INORGANIC PHOSPHORUS ON THE UPTAKE OF PHOSPHORUS BY RYE GRASS GROWN ON MOHAVE CLAY LOAM AND TUCSON SANDY LOAM.
Table 2. Phosphorus experiment -- yields and phosphorus uptake.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>P rate</th>
<th>Yield*</th>
<th>Fertilizer P in plant</th>
<th>Total P in plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs./A</td>
<td>gm.</td>
<td>gm.</td>
<td>mg.</td>
</tr>
<tr>
<td></td>
<td>Mohave clay loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>---</td>
<td>3.14</td>
<td>2.06</td>
<td>5.20</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>100</td>
<td>3.19</td>
<td>2.41</td>
<td>5.60</td>
</tr>
<tr>
<td>Extr. straw</td>
<td>---</td>
<td>1.08</td>
<td>1.83</td>
<td>2.91</td>
</tr>
<tr>
<td>KH₂PO₄ - extr. straw</td>
<td>100</td>
<td>1.42</td>
<td>1.99</td>
<td>3.41</td>
</tr>
<tr>
<td>0.25% P-straw</td>
<td>100</td>
<td>7.11</td>
<td>3.03</td>
<td>10.14</td>
</tr>
<tr>
<td>0.09% P-straw</td>
<td>100</td>
<td>4.84</td>
<td>2.95</td>
<td>7.89</td>
</tr>
<tr>
<td>0.25% P-straw</td>
<td>50</td>
<td>5.17</td>
<td>2.71</td>
<td>7.88</td>
</tr>
<tr>
<td>0.09% P-straw</td>
<td>50</td>
<td>4.10</td>
<td>2.15</td>
<td>6.25</td>
</tr>
<tr>
<td>0.68% P-straw</td>
<td>100</td>
<td>3.96</td>
<td>2.56</td>
<td>6.52</td>
</tr>
<tr>
<td>L.S.D. 5%</td>
<td></td>
<td>0.79</td>
<td>0.46</td>
<td>0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>lbs./A</th>
<th>gm.</th>
<th>gm.</th>
<th>mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tucson sandy loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>---</td>
<td>3.37</td>
<td>2.45</td>
<td>5.82</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>100</td>
<td>3.11</td>
<td>2.66</td>
<td>5.77</td>
</tr>
<tr>
<td>Extr. straw</td>
<td>---</td>
<td>1.42</td>
<td>2.23</td>
<td>3.65</td>
</tr>
<tr>
<td>KH₂PO₄ - extr. straw</td>
<td>100</td>
<td>1.22</td>
<td>2.29</td>
<td>3.51</td>
</tr>
<tr>
<td>0.25% P-straw</td>
<td>100</td>
<td>6.60</td>
<td>3.16</td>
<td>9.76</td>
</tr>
<tr>
<td>0.09% P-straw</td>
<td>100</td>
<td>1.17</td>
<td>0.63</td>
<td>1.80</td>
</tr>
<tr>
<td>0.25% P-straw</td>
<td>50</td>
<td>5.78</td>
<td>2.81</td>
<td>8.59</td>
</tr>
<tr>
<td>0.09% P-straw</td>
<td>50</td>
<td>1.18</td>
<td>0.81</td>
<td>1.99</td>
</tr>
<tr>
<td>0.68% P-straw</td>
<td>100</td>
<td>4.19</td>
<td>2.99</td>
<td>7.18</td>
</tr>
<tr>
<td>L.S.D. 5%</td>
<td></td>
<td>0.92</td>
<td>0.27</td>
<td>0.37</td>
</tr>
</tbody>
</table>

* Each figure represents the mean of three pots except those where 0.09 per cent P-straw was used which represents a mean of two pots and all figures were calculated on over-dry weight basis.
soil. Plants receiving the \( \text{KH}_2\text{PO}_4 \) treatment took up significantly higher amounts of phosphorus than those where straw containing 0.68 per cent phosphorus was used. The very low uptake of phosphorus by the crop from the Tucson soil treated with straw with 0.09 per cent phosphorus content indicates that phosphorus must have been immobilized in the soil possibly by the microorganisms during the decomposition process.

**Proportion of phosphorus in test crop taken from different sources.**

The uptake of phosphorus from the Mohave clay loam by the rye grass, from the straw residue added at the 50-pound rate was approximately one-half of that taken from the straw added at the 100-pound rate (Figure 3). For example, 1.27 mg. of phosphorus was taken up from the 50-pound treatment of straw containing 0.25 per cent P, whereas 2.30 mg. of phosphorus was taken up by the crop from this same source from the 100-pound treatment.

The data in Figure 3 indicate that the uptake of phosphorus from the straw treatment by rye grass on Mohave soil was not only directly proportional to the amount of phosphorus from the added source, but also proportional to the phosphorus content of the added source. For example, when the amounts of phosphorus absorbed by the rye grass from the soils receiving the two straws, one having 0.25 and the other
FIG. 3- THE UPTAKE OF PHOSPHORUS BY RYE GRASS ON MOHAVE CLAY LOAM AND TUCSON SANDY LOAM AS RELATED TO THE AMOUNT AND PERCENT OF PHOSPHORUS IN THE ADDED SOURCE.
0.09 per cent phosphorus applied at a rate of 100 pounds P per acre, were compared, it was found that the test crop absorbed 2.30 mg. of phosphorus from the straw having the highest phosphorus content and 0.82 mg. of phosphorus from the straw having the lowest phosphorus content.

Although the same straws were applied at the same levels to the Tucson sandy loam as to the Mohave soil, the proportions of phosphorus taken up from the straw residue were different (Figure 3 and Table 3). When phosphorus was added to the Tucson soil in the form of barley straw at the rate of 100 pounds P per acre, 2.39 mg. of phosphorus was taken up by the crop as compared to 1.50 mg. at the 50-pound rate. A much wider range in uptake was observed when comparisons were made between the straws containing 0.25 and 0.09 per cent phosphorus were added at the 50-pound rate. This difference in uptake probably was due to the immobilization of the available phosphorus from all sources by microbial activity.

Extracted straw appeared to affect the proportion of phosphorus taken up by the test crop from an added soluble source in the Mohave soil but not in the Tucson soil (Figure 4 and Table 3). For example, when phosphorus as KH₂PO₄ was added to the Mohave clay loam alone, 47.4 per cent of the phosphorus in the plant was taken up from this source. However, when the same amount of KH₂PO₄ was added to the
Table 3. The uptake of phosphorus by rye grass as influenced by applications of wheat straw.

<table>
<thead>
<tr>
<th>Materials added</th>
<th>Rate of phosphorus application</th>
<th>Phosphorus in straw*</th>
<th>Phosphorus from added source*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs./A</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Mohave clay loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KH$_2$PO$_4$</td>
<td>100</td>
<td>----</td>
<td>47.4</td>
</tr>
<tr>
<td>KH$_2$PO$_4$ - extr. straw***</td>
<td>100**</td>
<td>----</td>
<td>38.5</td>
</tr>
<tr>
<td>Straw 2</td>
<td>100</td>
<td>0.25</td>
<td>21.2</td>
</tr>
<tr>
<td>Straw 1</td>
<td>100</td>
<td>0.09</td>
<td>9.0</td>
</tr>
<tr>
<td>Straw 2</td>
<td>50</td>
<td>0.25</td>
<td>15.4</td>
</tr>
<tr>
<td>Straw 1</td>
<td>50</td>
<td>0.09</td>
<td>6.1</td>
</tr>
<tr>
<td>Tucson sandy loam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KH$_2$PO$_4$</td>
<td>100</td>
<td>----</td>
<td>43.0</td>
</tr>
<tr>
<td>KH$_2$PO$_4$ - extr. straw***</td>
<td>100**</td>
<td>----</td>
<td>43.9</td>
</tr>
<tr>
<td>Straw 2</td>
<td>100</td>
<td>0.25</td>
<td>20.4</td>
</tr>
<tr>
<td>Straw 1</td>
<td>100</td>
<td>0.09</td>
<td>10.3</td>
</tr>
<tr>
<td>Straw 2</td>
<td>50</td>
<td>0.25</td>
<td>18.6</td>
</tr>
<tr>
<td>Straw 1</td>
<td>50</td>
<td>0.09</td>
<td>8.7</td>
</tr>
</tbody>
</table>

* Calculated on oven-dry weight basis.

** Phosphorus as KH$_2$PO$_4$.

*** Phosphorus content of 0.01%.
MOHAVE CLAY LOAM

SOURCE OF P-\(\text{KH}_2\text{PO}_4\)
- 47.4 %

SOURCE OF P-\(\text{KH}_2\text{PO}_4+\text{EX. STRAW}\)
- 38.5 %

TUCSON SANDY LOAM

SOURCE OF P-\(\text{KH}_2\text{PO}_4\)
- 43.0 %

SOURCE OF P-\(\text{KH}_2\text{PO}_4+\text{EX. STRAW}\)
- 43.9 %

NOTE:

- PERCENT OF PHOSPHORUS IN RYE GRASS FROM ADDED SOURCES.

FIG. 4 - THE PERCENTAGE PHOSPHORUS IN THE RYE GRASS DERIVED FROM \(\text{KH}_2\text{PO}_4\) MIXED IN MOHAVE CLAY LOAM AND TUCSON SANDY LOAM ALONE OR WITH EXTRACTED STRAW.
soil with extracted straw, 38.5 per cent of phosphorus in the plant was absorbed from the added source. The absorption of phosphorus by rye grass from \( \text{KH}_2\text{PO}_4 \) applied to the Tucson soil after similar treatments was not appreciably affected by the straw since the data show that 43.0 per cent of the phosphorus in the test crop came from \( \text{KH}_2\text{PO}_4 \) in the absence of straw and 43.9 per cent came from the same source in the presence of straw.

The percentage phosphorus in the rye grass derived from the barley straw in Mohave clay loam was about proportional to the percentage of phosphorus originally in the added straw (Figure 5 and Table 3). As an illustration, the phosphorus content of the two straws used was 0.25 and 0.09 per cent, and the percentage of phosphorus in the test crop derived from the 100-pound applications was 21.2 and 9.0 per cent, respectively. This relationship was less striking where these straws were added at the lower rate of application.

The total uptake of native soil phosphorus in Mohave clay loam and Tucson sandy loam was influenced by the source of added phosphorus. The highest amount of native soil phosphorus taken up by the rye grass from both soils, as indicated by Figure 6, occurred when the straw containing 0.25 per cent phosphorus was added at the 100-pound phosphorus rate. Even application of the straw of the lowest concentration of phosphorus, 0.09 per cent, resulted in a greater total uptake of native soil
MOHAVE CLAY LOAM

TUCSON SANDY LOAM

100 LBS. P/A

100 LBS. P/A

P FROM STRAW 1   P FROM STRAW 2

P FROM STRAW 1   P FROM STRAW 2

50 LBS. P/A

50 LBS. P/A

P FROM STRAW 1   P FROM STRAW 2

P FROM STRAW 1   P FROM STRAW 2

P FROM SOIL

PERCENTAGE OF P IN TEST CROP DERIVED FROM STRAW.

RELATIONSHIP BETWEEN P CONTENT OF ADDED SOURCES

FIG. 5 - THE PROPORTION OF PHOSPHORUS IN THE RYE GRASS FROM THE ADDED SOURCE RESULTING FROM THE ADDITION OF STRAWS OF DIFFERENT PHOSPHORUS CONTENT TO MOHAVE AND TUCSON SOILS.
FIG. 6- TOTAL PHOSPHORUS UPTAKE FROM SOIL AND FROM ADDED SOURCE WHEN DIFFERENT RATES AND DIFFERENT FORMS OF PHOSPHORUS WERE ADDED TO MOHAVE AND TUCSON SOILS.
phosphorus by the rye grass in the Mohave clay loam than when a similar application rate of P was made in the form of KH$_2$PO$_4$. On the other hand, this same straw depressed the total uptake of phosphorus by the rye grass considerably below that taken from the soil alone when treated with inorganic phosphorus.

The availability of native soil phosphorus or "A" value.

The "A" value of a soil is dependent upon the plant absorbing the nutrient in question from two sources in the same proportion as that which is available from these sources. The method for determining the "A" value, as originally reported by Fried and Dean (13), requires the placing of a known amount of phosphate fertilizer labeled with radiophosphorus into a soil, growing a crop, measuring the proportion of phosphorus absorbed that was derived from the fertilizer, and calculating the amount of available phosphorus in the soil using the following equation:

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

Where

\begin{align*}
A & \text{ - amount of available phosphorus in the soil} \\
B & \text{ - amount of phosphorus in the fertilizer} \\
y & \text{ - proportion of phosphorus in the plant derived from the fertilizer.}
\end{align*}
Figure 7 and Table 4 indicate that the "A" values, as determined on plant material from Mohave clay loam and Tucson sandy loam under the conditions of this experiment, are very similar. When the two materials, KH$_2$PO$_4$ and KH$_2$PO$_4$ plus straw, were added to both Mohave and Tucson soils, the availability of soil phosphorus in each of the soils was nearly the same. This indicates, as has already been suggested, that the extracted straw did not affect the proportion of nutrients taken up by the plant from the soil and added source. The availability of the native nutrient in the soil should not be dependent on the amount of the nutrient added; however, the source of nutrient did affect the availability. The greater availability of native soil phosphorus in the presence of applications of barley straw as compared with KH$_2$PO$_4$ to both soils indicates that the decomposition of straw can and does affect the "A" value.

The Influence of Straw on the Availability of Native Soil Calcium to Rye Grass

The study of the influence of straw on the availability and uptake of native soil calcium offered greater problems than the study of the effect of straw on the availability of soil phosphorus. Calcium contamination was difficult to exclude, and calcium absorption by the plant varied more readily with changes in soil and air environment than phosphorus absorption. For this reason two experiments, almost duplicates,
FIG. 7—THE EFFECT OF THE ADDITION OF MINERAL PHOSPHORUS AND STRAW TO MOHAVE CLAY LOAM AND TUCSON SANDY LOAM ON THE 'A' VALUE OF PHOSPHORUS.
Table 4. The effect of addition of inorganic phosphorus and of straw at various levels of phosphorus on the uptake from these sources and from the soil.

<table>
<thead>
<tr>
<th>Materials added</th>
<th>Rate of P added</th>
<th>Phosphorus in plant from added source*</th>
<th>Total phosphorus in plant</th>
<th>Phosphorus &quot;A&quot; value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'lbs./A'</td>
<td>mg.</td>
<td>mg.</td>
<td>mg. 'lbs./A'</td>
</tr>
<tr>
<td>Mohave clay loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KH$_2$PO$_4$</td>
<td>100</td>
<td>3.74</td>
<td>2.57</td>
<td>6.97</td>
</tr>
<tr>
<td>KH$_2$PO$_4$ plus extr. straw</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100**</td>
<td>1.74</td>
<td>1.54</td>
<td>4.08</td>
</tr>
<tr>
<td>0.25% P straw</td>
<td>100</td>
<td>1.68</td>
<td>0.62</td>
<td>7.52</td>
</tr>
<tr>
<td>0.09% P straw</td>
<td>100</td>
<td>0.51</td>
<td>0.31</td>
<td>5.57</td>
</tr>
<tr>
<td>0.25% P straw</td>
<td>50</td>
<td>0.95</td>
<td>0.33</td>
<td>5.83</td>
</tr>
<tr>
<td>0.09% P straw</td>
<td>50</td>
<td>0.30</td>
<td>0.14</td>
<td>5.18</td>
</tr>
<tr>
<td>Tucson sandy loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KH$_2$PO$_4$</td>
<td>100</td>
<td>3.06</td>
<td>2.89</td>
<td>6.50</td>
</tr>
<tr>
<td>KH$_2$PO$_4$ plus extr. straw</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100**</td>
<td>1.73</td>
<td>1.97</td>
<td>3.49</td>
</tr>
<tr>
<td>0.25% P straw</td>
<td>100</td>
<td>1.70</td>
<td>0.70</td>
<td>8.57</td>
</tr>
<tr>
<td>0.09% P straw</td>
<td>100</td>
<td>0.16</td>
<td>0.05</td>
<td>1.33</td>
</tr>
<tr>
<td>0.25% P straw</td>
<td>50</td>
<td>1.02</td>
<td>0.41</td>
<td>5.56</td>
</tr>
<tr>
<td>0.09% P straw</td>
<td>50</td>
<td>0.08</td>
<td>0.05</td>
<td>1.04</td>
</tr>
</tbody>
</table>

* Each figure is the mean of three replications excepting those resulting from the application of 0.09% P straw which are the means of two replications.

** P as KH$_2$PO$_4$.
were undertaken. Radiostrontium was used in one experiment as a comparison with that of radiocalcium, since there is still some controversy regarding the claim that both are absorbed equally well, without differentiation, by plants.

Yield of the test crop, rye grass.

The yield of the rye grass test crop was more than doubled when straw was added to the Mohave clay loam as compared with the yield of rye from the soil alone (Figure 8 and Table 5). Laveen sandy loam treated with straw yielded one-half again as much as that from the soil only. The addition of 2 meq. of soluble calcium as a salt in solution to the Mohave and Laveen soils did not increase the yield of rye grass above that of the check treatment. Furthermore, the addition of extracted straw and extracted straw plus soluble calcium resulted in lower yields of the test crop than any of the other treatments.

In another experiment where both radiocalcium and radiostrontium were used, the same pattern of a positive influence of barley straw on yield and uptake of calcium by the test crop was observed (Figure 9 and Table 6). The dry weight of rye grass was significantly higher when straw residues containing radiostrontium and radiocalcium were added to the soil than when solutions of radiocalcium and radiostrontium in equivalent amounts were applied. Mohave clay loam receiving soluble
FIG. 8—THE INFLUENCE OF STRAW AND INORGANIC CALCIUM ON THE YIELD OF RYE GRASS ON MOHAVE CLAY LOAM AND LAVEEN SANDY LOAM.
Table 5. Yield of rye grass and total calcium uptake from two soils.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate of calcium added</th>
<th>Yield*</th>
<th>Total Ca Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>meq.</td>
<td>gm.</td>
<td>gm.</td>
</tr>
<tr>
<td>Mohave clay loam</td>
<td>None</td>
<td>5.22</td>
<td>2.88</td>
</tr>
<tr>
<td></td>
<td>0.15% Ca-straw</td>
<td>12.14</td>
<td>4.75</td>
</tr>
<tr>
<td></td>
<td>Extr. straw</td>
<td>2.37</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>(24.5 gm.)</td>
<td>1.68</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>Calcium + extr. straw</td>
<td>1.68</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>Calcium</td>
<td>3.36</td>
<td>2.34</td>
</tr>
</tbody>
</table>

L.S.D. 5%

<table>
<thead>
<tr>
<th>Laveen sandy loam</th>
<th>0.51</th>
<th>0.18</th>
<th>0.41</th>
<th>14.7</th>
<th>4.8</th>
<th>11.1</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate of calcium added</th>
<th>Yield*</th>
<th>Total Ca Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>meq.</td>
<td>gm.</td>
<td>gm.</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>5.27</td>
<td>2.59</td>
</tr>
<tr>
<td></td>
<td>0.15% Ca-straw</td>
<td>7.86</td>
<td>4.93</td>
</tr>
<tr>
<td></td>
<td>Extr. straw</td>
<td>1.37</td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td>(27.2 gm.)</td>
<td>1.20</td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>Calcium + extr. straw</td>
<td>1.20</td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>Calcium</td>
<td>3.36</td>
<td>2.63</td>
</tr>
</tbody>
</table>

L.S.D. 5%

|                     | 0.51 | 0.22 | 0.37 | 12.7 | 3.5 | 9.5 |

* Each figure is a mean of duplicate pots except those where inorganic calcium was added and the check pots which were triplicated. Figures were calculated on oven-dry weight basis.

** Ca in inorganic form.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dry Matter Grams</th>
<th>Total Calcium and Strontium Content (mg) Per Pot</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRAW (1 MEQ. Ca)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRAW (1 MEQ. Sr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX. STRAW 12.3 GM.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX. STRAW + 1 MEQ. Ca</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX. STRAW 27 GM.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EX. STRAW + 1 MEQ. Sr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHECK NONE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:**
- **1st Cutting**
- **2nd Cutting**
Table 6. The yield of dry matter and total uptake of calcium and strontium by rye grass grown on Mohave clay loam.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate Applied</th>
<th>Yield*</th>
<th>Total Ca-Sr Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crop 1</td>
<td>Crop 2</td>
</tr>
<tr>
<td></td>
<td>meq.</td>
<td>gm.</td>
<td>gm.</td>
</tr>
<tr>
<td>None</td>
<td>---</td>
<td>3.96</td>
<td>2.28</td>
</tr>
<tr>
<td>Ca-straw</td>
<td>1</td>
<td>5.79</td>
<td>2.88</td>
</tr>
<tr>
<td>Sr-straw</td>
<td>1</td>
<td>11.94</td>
<td>2.13</td>
</tr>
<tr>
<td>Extr. straw</td>
<td>---</td>
<td>1.49</td>
<td>0.83</td>
</tr>
<tr>
<td>27 gm.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extr. straw</td>
<td>---</td>
<td>2.87</td>
<td>1.08</td>
</tr>
<tr>
<td>12.3 gm.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr - 27 gm.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>extr. straw</td>
<td>1</td>
<td>1.25</td>
<td>1.42</td>
</tr>
<tr>
<td>Ca - 12.3 gm.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>extr. straw</td>
<td>1</td>
<td>3.00</td>
<td>1.46</td>
</tr>
<tr>
<td>Calcium</td>
<td>1</td>
<td>5.22</td>
<td>1.96</td>
</tr>
<tr>
<td>Strontium</td>
<td>1</td>
<td>4.13</td>
<td>1.93</td>
</tr>
<tr>
<td>L.S.D. 5%</td>
<td></td>
<td>0.62</td>
<td>0.40</td>
</tr>
</tbody>
</table>

* Each figure is a mean of duplicate pots except in treatments using inorganic calcium and strontium and the check which were triplicated.
radiocalcium also supported a significantly higher yield of rye grass than when no calcium was added. This result differed from that of the previous experiment where no effect of soluble radiocalcium was found. On the other hand, there was no significant difference in crop yields where radiostrontium was added compared with that of untreated soil.

Total calcium uptake by rye grass.

Total calcium uptake by the test crop from the Mohave clay loam was directly related to that of the yields of rye grass in the same soil (Figure 9 and Table 5). For example, the greatest yield of dry matter as well as total absorption was found in grass from soil receiving the natural straw. Extracted straw applications both with and without soluble calcium were always associated with the lowest yield of dry matter and calcium absorption. The grass grown on the soil receiving the straw containing radiostrontium resulted in a higher yield than that receiving the radiocalcium. This difference is also reflected in total uptake of calcium by the grass. The difference appears to be related to the different nature of the two straws and not to the difference in the irradiated cations since the uptake was reversed when the irradiated cations were added to the soil as a soluble salt without straw. The influence of straw on the uptake of calcium from the Laveen soil was different from that in the Mohave soil (Figure 10). The total amount of calcium taken up from
FIG. 10—THE INFLUENCE OF STRAW AND INORGANIC CALCIUM ON THE UPTAKE OF CALCIUM BY GRASS ON MOHAVE CLAY LOAM AND LAVEEN SANDY LOAM.
Laveen soil by the grass was greatest where neither straw, soluble calcium nor extracted straw had been added, i.e., the grass from the check pots absorbed more calcium than that from treated pots. The extracted straw appeared to depress calcium uptake in both the Mohave and Laveen soils (Figure 10). The finding in this experiment that calcium added to these soils, in a soluble form, depressed the total amount of calcium absorbed by the grass over that of the untreated soils is difficult to understand. This effect of calcium was not evident in the calcium-strontium experiment just discussed (see Figure 9).

**Proportion of calcium in rye grass from different sources.**

The amount of calcium absorbed by the rye grass from the straw residue was less than one per cent of the total taken up by the test crop. In spite of this wide ratio between added calcium and soil calcium, the straw appeared to influence markedly the uptake of native soil calcium. This is illustrated in Figure 9, where the rye grass from the Mohave clay loam treated with straw containing calcium absorbed more calcium and resulted in a higher yield than that obtained from any of the other treatments. It is not likely, however, that the calcium in the straw was responsible for the higher uptake. The straw influenced the yield of dry matter in some manner which in turn presumably resulted in a greater uptake of all plant nutrients from the soil as compared with the uptake from the untreated soil.
As in the case of the Mohave and Tucson soils, when phosphorus was the radioactive nutrient, the addition of extracted straw did not appreciably affect the amount of calcium absorbed by the rye grass from the radioactive calcium (Table 7). For example, the percentage of calcium in the rye grass derived from the added soluble source was 0.38 and 0.25 in one Mohave soil, 0.34 and 0.37 in Laveen soil in the absence and presence of extracted straw, respectively. When the rate of application was lowered to 1 meq. per 100 gm. of Mohave soil, the percentages were 0.23 and 0.21 in the absence and presence of extracted straw, respectively. If, as mentioned earlier, strontium is taken up by the plant about as readily as calcium, then the percentage absorption of strontium and calcium under similar experimental conditions should be about the same. This is apparent from the data in Table 7 under the subheading, Experiment 2. Not only was there little difference in the amount of radioactive calcium and radioactive strontium taken up by the plant when added to the Mohave soil in equivalent amounts, but the percentage of $^{45}$Ca and $^{89}$Sr in the plant derived from the added source, with and without extracted straw, was practically the same in all cases. From these results it may be concluded that the extracted straw does not influence the availability of native soil calcium.
Table 7. Uptake of calcium and strontium by rye grass as affected by calcium and strontium applied at different rates.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rate of application of Ca meq./pot</th>
<th>Total Ca uptake by crop* mg.</th>
<th>Ca or Sr in crop from added source %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mohave clay loam - Experiment 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>2</td>
<td>34.3</td>
<td>130</td>
</tr>
<tr>
<td>Ca + extr. straw</td>
<td>2</td>
<td>32.5</td>
<td>80</td>
</tr>
<tr>
<td>Laveen sandy loam - Experiment 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>2</td>
<td>38.7</td>
<td>130</td>
</tr>
<tr>
<td>Ca + extr. straw</td>
<td>2</td>
<td>24.0</td>
<td>90</td>
</tr>
<tr>
<td>Mohave clay loam - Experiment 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>1</td>
<td>47.2</td>
<td>110</td>
</tr>
<tr>
<td>Ca + extr. straw</td>
<td>1</td>
<td>28.5</td>
<td>60</td>
</tr>
<tr>
<td>Sr</td>
<td>1</td>
<td>37.5</td>
<td>80</td>
</tr>
<tr>
<td>Sr + extr. straw</td>
<td>1</td>
<td>29.1</td>
<td>60</td>
</tr>
</tbody>
</table>

* Each figure is a mean of three pots except where extracted straw was used which is a means of two.

** Strontium.
The availability of native soil calcium or "A" value.

When calcium, either in the form of barley straw or in soluble inorganic form, was added to the Mohave soil, there was no significant difference in the "A" values attributable to the addition of these materials (Figure 11 and Table 8). Apparently the addition of straw does not affect the availability of native soil calcium, as was previously shown for phosphorus. On the other hand, the straw lowered the availability of calcium in the Laveen soil. The reason for this is not clear, but it appears reasonable to assume that part of the soil calcium was needed for the decomposition of the straw. This assumption is made since it was found that (a) the calcium was about one-half as available in Laveen sandy loam as in Mohave clay loam, and (b) the "A" value of the Laveen soil was not affected by the addition of soluble inorganic calcium. The "A" value for calcium appears to be related to the exchangeable calcium of these two soils, which was 9.6 meq. per 100 gm. for the Laveen and 15.4 meq. per 100 gm. for the Mohave soil.

The Absorption of Strontium by Wheat and Alfalfa

Concentration of strontium in test crops.

Wheat and alfalfa differ markedly in their ability to absorb strontium from the soil. The concentration of Sr$^{89}$ in the wheat was only one-third to one-fourth the amount in the alfalfa per unit weight.
FIG. 11- THE EFFECT OF THE ADDITION OF INORGANIC CALCIUM AND STRAW TO MOHAVE CLAY LOAM AND LAWEEN SANDY LOAM ON THE 'A' VALUE OF CALCIUM.
Table 8. Calcium "A" values.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Ca added</th>
<th>Total Ca uptake</th>
<th>Ca from added source</th>
<th>&quot;A&quot; values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crop 1</td>
<td>Crop 2</td>
<td>Crop 1</td>
</tr>
<tr>
<td>Mohave clay loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.15% Ca-straw</td>
<td>36</td>
<td>85.9</td>
<td>28.4</td>
<td>0.42</td>
</tr>
<tr>
<td>Ca - extr. straw</td>
<td>36*</td>
<td>13.7</td>
<td>18.8</td>
<td>0.05</td>
</tr>
<tr>
<td>Calcium</td>
<td>36</td>
<td>18.8</td>
<td>15.5</td>
<td>0.09</td>
</tr>
<tr>
<td>Laveen sandy loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.15% Ca-straw</td>
<td>40</td>
<td>29.5</td>
<td>17.9</td>
<td>0.32</td>
</tr>
<tr>
<td>Ca - extr. straw</td>
<td>40*</td>
<td>9.8</td>
<td>14.2</td>
<td>0.05</td>
</tr>
<tr>
<td>Calcium</td>
<td>40</td>
<td>20.1</td>
<td>18.6</td>
<td>0.09</td>
</tr>
</tbody>
</table>

* Inorganic calcium.
The concentrations of added radiocalcium in the two crops also was found to be in about the same proportion. For example, wheat grown on Pima clay loam had 0.0018 per cent Sr\(^{89}\) and alfalfa 0.0054 per cent, whereas wheat contained 0.92 and alfalfa 2.52 per cent calcium. The ratio of strontium concentration between wheat and alfalfa was approximately 1:3 for all soils. About the same ratio of calcium concentration between these two crops also was found in practically all of the eight soils tested. This means that when comparing the absorption of strontium by two crops on the same soil, the crop that absorbs the greater amount of calcium will also absorb the greater amount of strontium.

It was mentioned in the introduction that there has been shown to be a reciprocal relation between exchangeable calcium content and the amount of strontium absorbed by the plant. This is further substantiated by the graph in Figure 12. A negative correlation coefficient of 0.90 was found between the logarithm of the exchangeable calcium and the concentration of Sr\(^{89}\) in the rye grass. This high correlation was found from the analysis of the first cutting of alfalfa grown on the eight soils listed in Table 1. However, a correlation coefficient of -0.89 was found when the average Sr\(^{89}\) concentration in both crops and from two cuttings was compared with the logarithm of the exchangeable calcium.
Table 9. The concentration of strontium and calcium in alfalfa and wheat grown on soils varying in exchangeable calcium content.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Exch. Ca</th>
<th>Alfalfa Sr*</th>
<th>Alfalfa Ca*</th>
<th>Wheat Sr*</th>
<th>Wheat Ca*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>meq./100'</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Pima clay loam</td>
<td>30.0</td>
<td>0.0054</td>
<td>2.520</td>
<td>0.0018</td>
<td>0.916</td>
</tr>
<tr>
<td>Mohave clay loam</td>
<td>15.4</td>
<td>0.0054</td>
<td>1.553</td>
<td>0.0020</td>
<td>0.558</td>
</tr>
<tr>
<td>Elliot silt loam</td>
<td>10.0</td>
<td>0.0065</td>
<td>1.670</td>
<td>0.0017</td>
<td>0.411</td>
</tr>
<tr>
<td>Laveen sandy loam</td>
<td>8.6</td>
<td>0.0103</td>
<td>1.971</td>
<td>0.0033</td>
<td>0.534</td>
</tr>
<tr>
<td>Tucson sandy loam</td>
<td>8.2</td>
<td>0.0124</td>
<td>2.002</td>
<td>0.0038</td>
<td>0.529</td>
</tr>
<tr>
<td>Fayette silt loam</td>
<td>6.7</td>
<td>0.0182</td>
<td>2.041</td>
<td>0.0047</td>
<td>0.550</td>
</tr>
<tr>
<td>Crosby silt loam</td>
<td>5.5</td>
<td>0.0253</td>
<td>2.000</td>
<td>0.0065</td>
<td>0.610</td>
</tr>
<tr>
<td>Norfolk fine sandy loam</td>
<td>2.0</td>
<td>0.0423</td>
<td>1.646</td>
<td>0.0187</td>
<td>0.605</td>
</tr>
</tbody>
</table>

* Each figure is a mean of three replications.
FIG. 12—THE RELATIONSHIP BETWEEN CONCENTRATION OF STRONTIUM IN RYE GRASS AND EXCHANGEABLE CALCIUM CONTENT OF "8" SOILS.
The calcium carbonate content did not appear to influence the strontium uptake by the crop. For instance, Laveen sandy loam had a $\text{CaCO}_3$ content of 4.14 per cent, (Table 1) and Tucson sandy loam 0.61 per cent, yet there appeared to be no significant difference between the amounts of strontium absorbed by wheat from these soils. The exchangeable calcium content was about the same in both soils.

The range of pH values of the soils used did not appear to affect the absorption of strontium by the crop. The crop containing the lowest concentration of strontium was grown on Pima clay loam with a pH value of 6.9, whereas Tucson sandy loam, at a pH value of 8.1, contained nearly double the concentration of strontium as the Pima soil. Wheat grown on Crosby silt loam with a pH value of 4.8 contained a concentration of strontium of only about a third of that found on Norfolk fine sandy loam, a soil with a pH value of 6.1. It is apparent, from these studies, that neither the pH value nor the $\text{CaCO}_3$ content of the soils treated affects the uptake of strontium by plants. The dominating factor appears to be the amount of exchangeable calcium in the soil.

The method for determining the "$k$" value or "distribution factor" for strontium in relation to calcium was explained in the introduction. It is based on the ratio of the percentage of available strontium to the percentage of available soil calcium taken up by a plant. When the "$k$" value approaches 1, the two elements under comparison are equally
available to the plant. The average "k" value of these elements for both wheat and alfalfa and for eight soils tested was 0.81 (Table 11). This indicates that, under the conditions of this experiment, strontium was about 81 per cent as available as calcium to wheat or alfalfa. There were no significant differences between the "k" values for wheat and alfalfa, but the differences of "k" values between soils were significant. This difference appears to be reciprocally related to the exchangeable soil calcium. The soil yielding the highest "k" value, Norfolk fine sandy loam, also contained the lowest exchangeable soil calcium. Two of the three soils having the highest exchangeable calcium yielded the lowest "k" values (Table 10). This indicates that the "k" value as determined by a plant species is influenced not so much by the species of plant as by the kind of soil on which the crop is grown.
Table 10. The "distribution factor" or "k" value for strontium as related to calcium in alfalfa and wheat grown on soils varying in exchangeable calcium content.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Soil Wt. per can</th>
<th>Dry Wt. plant*</th>
<th>Sr89 in plant*</th>
<th>Ca in plant*</th>
<th>Sr89 in soil</th>
<th>Ca in soil</th>
<th>D. F. value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg.</td>
<td>gm.</td>
<td>%</td>
<td>mg.</td>
<td>meq./100 gm.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>1st cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pima</td>
<td>2.0</td>
<td>2.19</td>
<td>0.0057</td>
<td>2.696</td>
<td>39.2</td>
<td>30.0</td>
<td>0.65</td>
</tr>
<tr>
<td>Mohave</td>
<td>3.0</td>
<td>3.85</td>
<td>0.0055</td>
<td>1.778</td>
<td>39.1</td>
<td>15.4</td>
<td>0.73</td>
</tr>
<tr>
<td>Elliot</td>
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<td>2.96</td>
<td>0.0073</td>
<td>1.968</td>
<td>39.1</td>
<td>10.0</td>
<td>0.57</td>
</tr>
<tr>
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<td>3.0</td>
<td>3.66</td>
<td>0.0113</td>
<td>2.150</td>
<td>38.9</td>
<td>8.6</td>
<td>0.69</td>
</tr>
<tr>
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<td>3.0</td>
<td>3.73</td>
<td>0.0138</td>
<td>2.222</td>
<td>38.8</td>
<td>8.2</td>
<td>0.78</td>
</tr>
<tr>
<td>Fayette</td>
<td>2.6</td>
<td>3.29</td>
<td>0.0181</td>
<td>2.212</td>
<td>38.7</td>
<td>6.7</td>
<td>0.74</td>
</tr>
<tr>
<td>Crosby</td>
<td>2.5</td>
<td>2.99</td>
<td>0.0263</td>
<td>2.020</td>
<td>38.5</td>
<td>5.5</td>
<td>0.93</td>
</tr>
<tr>
<td>Norfolk</td>
<td>3.5</td>
<td>1.69</td>
<td>0.0460</td>
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<td>38.5</td>
<td>2.0</td>
<td>0.78</td>
</tr>
<tr>
<td>-- 2nd cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pima</td>
<td>2.0</td>
<td>5.83</td>
<td>0.0052</td>
<td>2.343</td>
<td>39.0</td>
<td>30.0</td>
<td>0.68</td>
</tr>
<tr>
<td>Mohave</td>
<td>3.0</td>
<td>4.80</td>
<td>0.0053</td>
<td>1.328</td>
<td>39.1</td>
<td>15.4</td>
<td>0.94</td>
</tr>
<tr>
<td>Elliot</td>
<td>3.0</td>
<td>3.79</td>
<td>0.0057</td>
<td>1.333</td>
<td>39.1</td>
<td>10.0</td>
<td>0.66</td>
</tr>
<tr>
<td>Laveen</td>
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<td>1.43</td>
<td>0.0093</td>
<td>1.793</td>
<td>39.2</td>
<td>8.6</td>
<td>0.69</td>
</tr>
<tr>
<td>Tucson</td>
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<td>5.49</td>
<td>0.0110</td>
<td>1.783</td>
<td>38.5</td>
<td>8.2</td>
<td>0.79</td>
</tr>
<tr>
<td>Fayette</td>
<td>2.6</td>
<td>5.82</td>
<td>0.0182</td>
<td>1.872</td>
<td>38.3</td>
<td>6.7</td>
<td>0.88</td>
</tr>
<tr>
<td>Crosby</td>
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<td>6.36</td>
<td>0.0243</td>
<td>1.987</td>
<td>37.8</td>
<td>5.5</td>
<td>0.89</td>
</tr>
<tr>
<td>Norfolk</td>
<td>3.5</td>
<td>6.00</td>
<td>0.0385</td>
<td>1.145</td>
<td>37.0</td>
<td>2.0</td>
<td>1.27</td>
</tr>
</tbody>
</table>
Table 10. (cont’d) The "distribution factor" or "k" value for strontium as related to calcium in alfalfa and wheat grown on soils varying in exchangeable calcium content.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Soil Wt.</th>
<th>Dry Wt.</th>
<th>Sr$^{89}$ in plant*</th>
<th>Ca in plant*</th>
<th>Sr$^{89}$ in soil</th>
<th>Ca in soil</th>
<th>D. F. value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per can</td>
<td>gm.</td>
<td>%</td>
<td>%</td>
<td>mg. /100 gm.</td>
<td>meq. /100 gm.</td>
<td></td>
</tr>
<tr>
<td>Wheat -- 1st cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pima</td>
<td>2.0</td>
<td>14.25</td>
<td>0.0023</td>
<td>1.232</td>
<td>39.0</td>
<td>30.0</td>
<td>0.57</td>
</tr>
<tr>
<td>Mohave</td>
<td>3.0</td>
<td>10.58</td>
<td>0.0021</td>
<td>0.612</td>
<td>39.1</td>
<td>15.4</td>
<td>0.81</td>
</tr>
<tr>
<td>Elliot</td>
<td>3.0</td>
<td>11.83</td>
<td>0.0018</td>
<td>0.505</td>
<td>39.1</td>
<td>10.0</td>
<td>0.55</td>
</tr>
<tr>
<td>Laveen</td>
<td>3.0</td>
<td>10.37</td>
<td>0.0032</td>
<td>0.551</td>
<td>39.0</td>
<td>8.6</td>
<td>0.76</td>
</tr>
<tr>
<td>Tucson</td>
<td>3.0</td>
<td>9.95</td>
<td>0.0041</td>
<td>0.595</td>
<td>38.9</td>
<td>8.2</td>
<td>0.87</td>
</tr>
<tr>
<td>Fayette</td>
<td>2.6</td>
<td>13.21</td>
<td>0.0051</td>
<td>0.607</td>
<td>38.6</td>
<td>6.7</td>
<td>0.76</td>
</tr>
<tr>
<td>Crosby</td>
<td>2.5</td>
<td>16.56</td>
<td>0.0069</td>
<td>0.693</td>
<td>38.2</td>
<td>5.5</td>
<td>0.72</td>
</tr>
<tr>
<td>Norfolk</td>
<td>3.5</td>
<td>6.65</td>
<td>0.0228</td>
<td>0.630</td>
<td>37.8</td>
<td>2.0</td>
<td>1.34</td>
</tr>
</tbody>
</table>

-- 2nd cutting

<table>
<thead>
<tr>
<th>Soil</th>
<th>Soil Wt.</th>
<th>Dry Wt.</th>
<th>Sr$^{89}$ in plant*</th>
<th>Ca in plant*</th>
<th>Sr$^{89}$ in soil</th>
<th>Ca in soil</th>
<th>D. F. value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per can</td>
<td>gm.</td>
<td>%</td>
<td>%</td>
<td>mg. /100 gm.</td>
<td>meq. /100 gm.</td>
<td></td>
</tr>
<tr>
<td>Pima</td>
<td>2.0</td>
<td>4.77</td>
<td>0.0014</td>
<td>0.600</td>
<td>39.3</td>
<td>30.0</td>
<td>0.71</td>
</tr>
<tr>
<td>Mohave</td>
<td>3.0</td>
<td>3.74</td>
<td>0.0020</td>
<td>0.505</td>
<td>39.2</td>
<td>15.4</td>
<td>0.93</td>
</tr>
<tr>
<td>Elliot</td>
<td>3.0</td>
<td>3.04</td>
<td>0.0016</td>
<td>0.317</td>
<td>39.3</td>
<td>10.0</td>
<td>0.77</td>
</tr>
<tr>
<td>Laveen</td>
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<td>3.25</td>
<td>0.0034</td>
<td>0.518</td>
<td>39.2</td>
<td>8.6</td>
<td>0.86</td>
</tr>
<tr>
<td>Tucson</td>
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<td>3.72</td>
<td>0.0036</td>
<td>0.463</td>
<td>39.2</td>
<td>8.2</td>
<td>0.98</td>
</tr>
<tr>
<td>Fayette</td>
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<td>2.67</td>
<td>0.0044</td>
<td>0.493</td>
<td>39.2</td>
<td>6.7</td>
<td>0.79</td>
</tr>
<tr>
<td>Crosby</td>
<td>2.5</td>
<td>8.65</td>
<td>0.0061</td>
<td>0.528</td>
<td>38.8</td>
<td>5.5</td>
<td>0.82</td>
</tr>
<tr>
<td>Norfolk</td>
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<td>3.48</td>
<td>0.0185</td>
<td>0.580</td>
<td>38.7</td>
<td>2.0</td>
<td>1.16</td>
</tr>
</tbody>
</table>

*Mean of three determinations.
Table 11. Summary of "k" values for soils and crops.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Alfalfa</th>
<th>Wheat</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st cut.</td>
<td>2nd cut.</td>
<td>1st cut.</td>
</tr>
<tr>
<td>Pima</td>
<td>0.65</td>
<td>0.68</td>
<td>0.57</td>
</tr>
<tr>
<td>Mohave</td>
<td>0.73</td>
<td>0.94</td>
<td>0.81</td>
</tr>
<tr>
<td>Elliot</td>
<td>0.57</td>
<td>0.66</td>
<td>0.55</td>
</tr>
<tr>
<td>Iaveen</td>
<td>0.69</td>
<td>0.68</td>
<td>0.76</td>
</tr>
<tr>
<td>Tucson</td>
<td>0.78</td>
<td>0.79</td>
<td>0.87</td>
</tr>
<tr>
<td>Fayette</td>
<td>0.74</td>
<td>0.88</td>
<td>0.76</td>
</tr>
<tr>
<td>Crosby</td>
<td>0.93</td>
<td>0.89</td>
<td>0.72</td>
</tr>
<tr>
<td>Norfolk</td>
<td>0.78</td>
<td>1.27</td>
<td>1.37</td>
</tr>
<tr>
<td>Average</td>
<td>0.73</td>
<td>0.84</td>
<td>0.80</td>
</tr>
</tbody>
</table>

L.S.D. 5% For crops 0.17
For soils 0.16
Radioactive phosphorus, calcium, and strontium were used to distinguish between the test nutrient that was absorbed from straw, liquid fertilizer, and from the soil. Thus, the evaluation of the added source could be assessed directly on the basis of its measured absorption by the plant as well as indirectly on a basis of yield response.

Barley straw mixed with Mohave and Tucson soils was shown to be a valuable source of phosphorus to crops grown under greenhouse conditions. The principal factors studied were those inherent in the straw rather than those not a part of the residues such as temperature, moisture, or soil.

The fixation of inorganic phosphorus by the soil in difficultly available form may be reduced by the addition of straw residues to the soil. This was indicated by increased yields and in some cases by as great a phosphorus uptake from the straw as when inorganic phosphorus was added in equivalent amounts.

When phosphorus was added to Mohave clay loam in the form of barley straw, the crop absorbed the added nutrient in direct proportion to the amount of phosphorus added. This was not as evident in the Tucson
sandy loam as in the Mohave clay loam, but the difference did not appear significant.

There appeared to be a definite indication that the total phosphorus content of the crop varies with the percentage of phosphorus in the straw added. This is in agreement with data presented by Fuller, Nielsen, and Miller (19).

A depressing influence of straw having a low phosphorus content, 0.09 per cent P, on the yield of rye grass and on the phosphorus content of the grass was apparent in the Tucson soil. The threshold value for straw above which additional phosphorus is not needed for decomposition is about 0.20 per cent according to Fuller, et al. (19). The fact that straw depressed the growth of grass in the Tucson soil and not the Mohave indicates that there was more soil phosphorus available to the crop in the Mohave soil. Nitrogen was not limiting since the C:N ratio was below 30. As indicated in Figure 7 the "A" value of phosphorus resulting from these two treatments at the 0.09 per cent phosphorus level is different in these two soils, whereas in practically all the other treatments no significant differences were observed. In this case the "A" value for the Mohave soil was 50 per cent larger than that for the Tucson soil. The available phosphorus was utilized by microbial action at the expense of the crop. Fuller and Rogers (20) found that when the C:P ratio rises above 1:200, phosphorus becomes unavailable to the plant.
It was found that when \( \text{KH}_2\text{PO}_4 \) and \( \text{KH}_2\text{PO}_4 \) plus extracted straw were added to the Mohave and Tucson soils, the ratios of added phosphate to that in the plant from the added source were about the same. If, as was indicated, the extracted straw did not affect these ratios, then similar results might be expected in the calcium and strontium experiments. The principal difference being that the plants would not lack any of the essential nutrients, that is, the crop would be supplied N, P, and K beyond its minimum needs. Calcium should not be lacking since the soils used were calcareous. This removes the possibility of side effects due to an insufficient amount of one nutrient. This was indicated in the phosphorus experiment when a very low uptake of phosphorus by rye grass from the 100- and 50-pound-per-acre treatments occurred on Tucson sandy loam, a phosphorus-deficient soil. The 1:1 ratio was not so evident in the calcium as in the phosphorus study. With Mohave clay loam, ratios of 1:1 and 1:1.5 were obtained in duplicate experiments. The reason for this variation is not known. The evidence now available does indicate that extracted straw does not appreciably affect the percentage uptake of phosphorus relative to the whole P content of the crop.

One factor in the straw that appears to benefit plant growth is the nutrient content. In both the phosphorus and calcium experiments, a greater yield was observed when the crop was provided with straw containing the test nutrient as compared with those in which no straw was
added. This may not be due to the specific nutrient in question, i.e., phosphorus or calcium, but when the decomposing straw can supply all the essential nutrients for microbial action, then the decomposition can proceed at a normal rate and no excessive demand is made upon the soil for these nutrients at the expense of the growing plant.

In all cases a greater uptake of the test nutrient was from a straw except in the phosphorus experiment, where inorganic phosphorus had been added. However, in this case the yield of dry matter was not significantly higher than from the check treatment. In the calcium experiment where a high uptake was found, the yield of rye grass on soil alone was below that of the soils treated with straw. It may be that the nutrients are released from the straw by microbial action at such a rate, in such quantities, or in such a form as to provide optimum conditions for plant development. The rate factor may be indicated by the differences in yields between those resulting from treatments with inorganic phosphorus as compared with straw phosphorus. The inorganic phosphorus was water soluble, immediately available for fixation in the soil, whereas the phosphorus from the straw would necessarily be released gradually and possibly at a time when most needed by the plant. A similar condition was evident in the calcium experiments where rye grass, grown on the untreated Laveen soil, exhibited a high calcium content, yet the yield was lower than from the same soil treated with straw.
As Nielsen, Pratt, and Martin (33) indicated in an experiment using alfalfa straw, the availability of native phosphorus is markedly affected by the addition of straw. This does not invalidate the "A" value concept because it is based on the ratio of amounts of an available nutrient from two sources. Microbial action may affect the availability of a plant nutrient from the decomposing straw much more than from the soil. When this occurs, the ratio of the amount of nutrient the plant absorbs from the straw to that absorbed from the soil is changed, which will in turn change the "A" value.

Collander (9) points out that the absorption of strontium by plants does not obey the general rule that "the absorption ratio of a given ion increases when the concentration of that ion in the medium decreases." The results of the strontium study reported here indicate that an increasing amount of strontium was absorbed as the concentration of calcium increased. This can be explained by assuming that the ions of calcium and strontium, in their absorption by plants, behave as identical ions or as two isotopes of the same element. Collander, reporting on a wide variety of plants grown in nutrient solutions, states further that all plants absorb rubidium, cesium, and potassium with about the same rapidity. He found that calcium and strontium also were absorbed by plants about equally well.
The "k" value of strontium to calcium, as determined by growing wheat and alfalfa on eight different soils, had an average value of 0.81. This indicates that strontium is absorbed by plants approximately as readily as calcium. As would be expected, the "k" value did not vary significantly between plant species, but it varied from 0.67 to 1.20 between soils. This may be the reason for the lower "k" value (0.40) as reported by Menzel and Heald (32) using a number of soils varying in exchangeable calcium. As mentioned earlier, Menzel (31) showed that there existed an inverse relationship between the absorption by plants of strontium and the amount of exchangeable calcium in the soil. He also found a similar inverse proportionality between rubidium and cesium to exchangeable potassium. Potassium, rubidium, and cesium are in the group of alkali metals as are calcium, strontium, and barium in Group II of alkaline earths. One of the similarities of this group is that all of the alkaline earth metals can form doubly-charged positive ions in solution. The fact that calcium and strontium are in the same group, the difference in their atomic numbers being 18, would indicate that their chemical properties are very closely related.
SUMMARY

1. The influence of organic residues such as straw on the availability of native soil phosphorus and calcium was studied in three calcareous soils -- Mohave clay loam, Tucson sandy loam, and Laveen sandy loam under greenhouse conditions.

2. An additional investigation was made to determine the "distribution factor" of calcium and strontium in alfalfa and wheat grown on four acid and four calcareous soils.

3. The radiotracer technique was used in these studies whereby experimental straw were prepared by growing barley in nutrient solutions containing radioactive phosphorus, calcium, and strontium.

4. In all cases where phosphorus was added in the form of straw containing P above 0.20 per cent, more native soil P was taken up by the test crop in the presence of straw than from the soil treated with an equivalent amount of inorganic phosphorus. Calcium absorption by rye grass was enhanced by the presence of straw in Mohave clay loam but depressed by straw in Laveen sandy loam. The difference is explained on the basis of the Mohave soil having a greater amount of exchangeable calcium than the Laveen soil.
5. The "A" value, or availability, of native soil phosphorus and calcium was affected by the amounts of straw added as well as by the nutrient composition of the straw.

6. When radiophosphorus in a straw was added to Mohave clay loam, it was absorbed by rye grass in direct proportion to the amount added. This direct proportion was not quite so evident in the Tucson soil as in the Mohave soil. This difference is due to the fact that the Mohave soil was better supplied with available P than the Tucson soil.

7. The data indicate that the phosphorus uptake from all sources by the test crop on Mohave and Tucson soils was almost directly proportional to the phosphorus content of the added straw.

8. Straw with a wide carbon:phosphorus ratio was found to decrease the yield of the test crop. This wide ratio of extracted straw did not appreciably affect the ratio of added nutrient in the soil to the total nutrient taken up by the plant.

9. In many instances phosphorus and calcium were taken up and utilized by rye grass more effectively from straw than from a purely inorganic source.

10. The "k" value or "distribution factor" of strontium to calcium was the same for wheat and alfalfa, but there was a significant variation between soils. This variation was related to the exchangeable calcium in the soils. The average "k" value of all eight soils and crops tested was 0.81.
11. The absorption of strontium by wheat and alfalfa from soils having a wide range of exchangeable calcium was shown to be inversely proportional to the exchangeable calcium. This relationship was statistically significant.

12. The CaCO₃ in the four calcareous soils apparently did not influence the uptake of strontium by wheat or alfalfa to the same extent as did the exchangeable calcium.

13. The concentration of strontium in wheat in any one of the eight soils tested was approximately one-third that of strontium in alfalfa in the same soils.
BIBLIOGRAPHY


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