THE INFLUENCE OF CROP RESIDUES ON THE AVAILABILITY TO PLANTS OF NATIVE SOIL CALCIUM AND PHOSPHORUS

By

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TABLE OF CONTENTS

Page

Page

LIST OF EXPERIMENTAL DATA

Tables

Figures

INTRODUCTION

Large quantities of organic materials are plowed into the soil in the form of manure, green manure, or mature straw, to serve as sources of elements essential for plant growth. It is believed that these decomposing organic materials influence the solubility of nutrient elements already present in the soil. Conflicting reports have developed on this subject because the investigators were not able to distinguish between the effects of the nutrients already in the soil and nutrients added by the organic material.

Bear, *et al*. (1)* and Copeland and Merkle (7) report that manure is an effective source of phosphorus despite its low phosphorus content. Geriche (17) concludes from data of numerous fertilization experiments that P_2O_5 of manure is inferior to that in inorganic forms. Guyon (18) found that plants utilized less phosphorus from manure than from common inorganic sources, however Dorph-Peterson (9) reports equal uptake of phosphorus from both sources.

Decoux and Simon (8) feel that direct plowing under of straw is not a good practice since this practice may immobilize available nutrients. Chaminade (5), using culture solutions, states that calcium-humate increased the uptake of N, P, K, Ca, Mg by rye, but did not increase yields.

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

Hoffman, et al. (22) using greenhouse soils that had been fertilized for many years, reports that there were no significant differences in tomato yields between straw and hay mulches or between the check plot and those receiving CaO, manure or chemical fertilizer.

The usual method of evaluating organic materials as used by the above investigators was based upon yield response or increased uptake of a particular nutrient by a plant. For example:

$$\%\ P\ \text{utilization} = \frac{\text{Total P in plant} - \text{P in check plant}}{\text{Total P added}} \times 100$$

However, yield response and nutrient uptake often interact with environmental factors that effect plant growth. With the discovery of induced radioactivity by Curie in 1932, and the development of the atomic pile during the war, a new tool was made available for research in the biological sciences. For example, the percentage of phosphorus utilized by a crop maybe calculated from the basic formula:

$$\%\ P\ \text{utilization} = \frac{\text{Total Radioactive P in plant}}{\text{Total radioactive P added}} \times 100$$

Thus, it is possible to determine the uptake of nutrients by plants from an added residue by the radiotracer method of analysis (14,31) -- a great advance over previous techniques.

Because the research reported here involves the influence of crop residues on the availability of native calcium and phosphorus, the recent literature on this subject will be reviewed briefly. The uptake of strontium, as a contaminant in soil from possible nuclear reactions of uranium fission is also a part of this study. Its uptake is similar to that of calcium.

Calcium Uptake

Calcium is an element essential to plant growth. Combining with pectic acid, it forms calcium pectate, a constituent of the cell wall middle lamella. No new cell walls are laid down when calcium becomes limiting.

When calcium is added to acid soils it is usually applied in the form of limestone - calcium and magnesium carbonate. Lime is not, strictly speaking, a fertilizer but is a soil amendment applied to correct soil acidity. One of its functions however, is to supply calcium to the plant if the soil is deficient in this element.

Harris, *et al.* (20) have shown by using radioactive calcium, that with increasing amounts of applied calcium carbonate to acid soils, the calcium content of the plants increased from this source. Fried and Peech (13) report that plants absorb more calcium from acid soils treated with lime than those treated with gypsum. Schmehl, *et al.* (30) suggest that antagonism from aluminum, manganese, and hydrogen ions cause low calcium content in plants of acid soils. With the application of calcium carbonate, the concentration of the antagonists were reduced and calcium absorption increased.

It is generally assumed that calcium nutrition is not a problem of any consequence in alkaline-calcareous soils. However, due to the great difference in the solubility of the calcium salts in soils, soluble calcium may be low. For example, in the more alkaline soils the soluble bicarbonate salts do not exist, (27). The amount of water-soluble calcium in 10 calcareous Arizona soils was found to be almost nil according to Flocker (11).

When irrigation water is added to calcareous soils, the chemical reaction taking place, according to Buehrer and Williams (4), is as follows:

$$CaCO_{3(solid)} + H_2O_{(liquid)} = Ca^{++} + HCO_3^- + OH^-$$

The rate of this reaction, however is dependent upon many factors present in a single soil. The solubility constant of calcium carbonate in Arizona soils is believed to be very low (10).

Fuller and Flocker (15) found that the absorption of calcium from calcareous soils was not correlated with the percentage of calcium carbonate in arid soils. Calcium uptake however, was proportional to the exchangeable calcium. Brown and Albrecht (3) postulated that by increasing the percentage calcium carbonate in the soil, whether acid or calcareous, caused a monopoly of calcium on the base exchange complex. Borland and Reitermeier (2) using radioactive calcium, showed that exchangeable calcium maintained an equilibrium with soluble calcium. Thus it appears from the investigations by Fuller and Flocker, and Borland and Reitemeier that exchangeable calcium can serve as an indicator of calcium available to the plant.

A quantitative estimate of the relative efficiency or availability of an organic material to supply nutrients to the succeeding crop can be made by an extension of the technique which utilizes radioactive labeled fertilizer. Fried and Dean (12) suggest that "availability" implies that when more than one source of a given nutrient is present in the soil, the plant will absorb the nutrient from the various sources in proportion to the amount present in the respective sources. Mathmatically the equation may be expressed:

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

Where:

A = the amount of available nutrient in the soil

B = the amount of nutrient in the standard

Y = the proportion of the nutrient in the plant derived from the standard.

Strontium Uptake

Strontium is considered the most hazardous material released in fission of uranium. The element is readily absorbed by plants from contaminated soils and concentrated in their tissues. Animals and humans who eat crops contaminated with radiostrontium further concentrate the element in their bodies.

Strontium is not considered to be essential to plant growth. Hazelhoff (21) postulates that strontium can take the place of calcium as a plant nutrient when the latter is deficient. Jacobson and Overstreet (24) using calcium-bentonite suspensions found that strontium will replace calcium in dwarf pea plants. In an earlier investigation (23) they found that the maximum cation uptake occurred near the growing point of the root and that strontium was absorbed from solutions at extremely low concentrations. Collander (6) observed that in nutrient solutions containing both calcium and strontium in various concentrations, each of these cations was absorbed in amounts directly proportional to the concentration of that ion in solution. It therefore appears that a plant cannot distinguish between calcium and strontium and that they will absorb one element about as readily as the other.

Menzel (28) studied the competitive uptake of strontium and calcium by growing plants. Using cowpeas as the test plant on 42 soils, he found that the ratio of Sr^{89} to Ca in the plant was inversely proportional to the exchangeable calcium content of the plant. Fuller and Flocker (15) using 10 calcareous and 3 forest soils, found that the uptake of added soluble radiostrontium was not related to the total calcium nor the calcium carbonate content of the different calcareous soils, but was related rather to the exchangeable calcium.

Phosphorus Uptake

Phosphorus is an essential element for plant growth. It is believed to stimulate early growth and root formation, hasten maturity, promote seed production, and contribute to the general hardiness of the plant. Phosphorus is also an active component of protoplasm.

Organic residues such as manures (9) and alfalfa green manure (26,29) have been reported to supply phosphorus to plants in amounts nearly as great as, if not greater than, wholly soluble phosphate such as KH_2PO_4. Fuller and Dean (14) report that green manure supplied 70 per cent as much phosphorus to the succeeding crop as did superphosphate applied on an equivalent phosphate basis. This same investigation revealed a high probability that absorption of phosphorus from manure might be an inverse function of the phosphorus supplying power of the soil.

McAuliffe, et al. (26) and Nielsen, et al. (29) using acid soils, found that the phosphorus in green alfalfa manure was not as available as that of KH_2PO_4 and that the alfalfa manure increases the availability of the residual soil phosphorus.

Phosphorus in organic material becomes available for plant use as a result of microbial decomposition. The release of biologically fixed phosphorus is not instantaneous, but proceeds at a rate corresponding more or less to that of the decomposition of the material under consideration. Nielsen, et al. (29) carried out Neubauer tests, which indicated that the phosphorus from green alfalfa manure is most available during the period between 46 and 64 days after being mixed into the soil.

Phosphorus in organic material is only temporarily fixed. Unlike inorganic fixation, organic phosphorus eventually may become wholly available for plant use. According to Hannapel (19) increasing the carbon to nitrogen ratio, increased the rate of decomposition of organic residues and thus increased the rate and quantities of nutrient made available for plant use. Fuller, et al. (16) studied the factors that influence the rate of release of phosphorus from plant residues added to soils in terms of the amount of residue phosphorus absorbed by the succeeding crop. The investigators observed that the amount of phosphorus absorbed by ryegrass from crop residues was inversely related to the maturity of the residue. In addition, they observed that the percentage of phosphorus in the test crops derived from the crop residue added to soils, was found to increase directly as the phosphorus content of the crop residue increased.

Object of the Investigation

The object of this investigation was:

(1) to study the influence of decomposing plant residues added to calcareous soils on the uptake by plants of added soluble Ca^{45}* and Sr^{89}**,

(2) to measure the availability of native soil calcium by the "A" value technique as influenced by the presence of crop residues added to the soil and,

(3) to determine the influence of crop residues on the availability of native soil phosphorus.

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*Calcium 45 represents an irradiated sample of calcium carbonate.

**Strontium 89 represents an irradiated sample of strontium nitrate.

EXPERIMENTAL MATERIAL FOR CALCIUM AND STRONTIUM EXPERIMENT

Soils

The 4 soils used were described and analyzed by Flocker (12). They are presented in Table 1. The soils were collected from the top 6-inch layer in the following locations: Mohave sandy clay loam - a red desert soil on an alluvial fan in the Salt River Valley near Chandler, Arizona. Pima clay loam, Laveen sandy loam, and Tucson sandy loam are alluvial soils of the calcareous desert area located in the Santa Cruz Valley near Tucson, Arizona

The 4 soils used for these investigations were selected because they varied in exchangeable calcium and total calcium carbonate. Pima clay loam is high in exchangeable calcium but low in total calcium carbonate. Laveen sandy loam is low in exchangeable calcium but high in total calcium carbonate. Mohave sandy clay loam has the lowest percent of calcium carbonate content however is intermediate in exchangeable calcium. Tucson sandy loam is low in both calcium carbonate and exchangeable calcium.

Composition of Extracted Oat Straw

The composition of the extracted oat straw as measured by the Beckman D.U. flame photometer was 0.07 per cent calcium, 0.05 per cent potassium and 0.01 per cent sodium.

TABLE 1. SOME CHEMICAL CHARACTERISTICS OF FOUR CALCAREOUS ARIZONA SOILS.

Soil Type	Cation exchange capacity	Exchangeable Cations			pH of paste	Calcium Carbonate	CO_2-Soluble Phosphorus
		Ca*	Na	K			
	m.e./100 gm.	m.e./100 gm.				per cent	p.p.m.
Mohave sandy clay loam	18.5	15.4	1.3	1.8	7.29	0.077	Trace
Tucson sandy loam	8.4	7.5	0.4	0.5	8.22	1.530	1.5
Pima clay loam	40.5	30.0	4.8	5.7	7.40	1.560	8.5
Laveen sandy loam	6.4	5.0	0.6	0.8	8.37	11.390	4.9

* Determined by difference.

EXPERIMENTAL METHODS

Preparation of Extracted Oat Straw

Mature oat straw, ground to pass a 40 mesh screen, was saturated with 1 per cent sodium hydroxide and washed with distilled water in a Buchner funnel. The washed straw was then treated with 1 per cent hydrochloric acid and re-washed with distilled water to remove the salts and until it was neutral. The extracted straw was dried in an oven at 65°C and screened to break up the lumps.

Preparation of Radioactive Calcium and Strontium Solutions

Radioactive calcium carbonate, in powder form, was dissolved in dilute hydrochloric acid. Strontium nitrate, in powder form, was dissolved in distilled water. Both solutions were then further diluted in distilled water so that the aliquot required for soil treatment would be of convenient volume.

Plant Analysis

The tomato residues were oven dried at 60°C and ground in a Wiley mill fitted with a 40 mesh screen. Samples of the residues were weighed into 50 ml. beakers and ashed at 550°C for 4 hours. Then, 25 ml of 0.1N hydrochloric acid was added to the cool ash and the mixture was allowed to stand for 1 hour before filtering through a Whatman No. 30 filter paper into a 50 ml volumetric flask. The acid-filtrate was then analyzed photometrically for total calcium, sodium, and potassium by use of the Beckman D.U. flame photometer. The cation content of the plant was expressed as weight percentage on the dry weight basis.

Measurement of Radioactivity

The amount of radiocalcium or radiostrontium absorbed by the plant was measured from the acid-filtrate of the plant ash. A known aliquot of the filtrate was placed on a aluminum planchet and allowed to dry. An aliquot from the standard solution that was prepared originally for use in soil treatments was prepared in the same way. The radioactivity of the dried filtrate was determined by fitting the planchet into an alpha-beta-gamma proportional internal-gas-chamber counter built by the Nuclear Measurements Corporation, Model PC-3. Countings were made in the Gieger Muller range.

The percentage of the radioactivity in the plant was calculated by using the standard solution. The concentration of element in the standard was known. Its concentration and rate of radioactive disintegration is proportional to that of the radioactive nutrient absorbed by the plants.

The percentage uptake of the radioactive element was found by dividing the radioactivity of the planchet material by the specific activity of the solution added to the soil times 100.

$$\frac{\text{counts/min./mgm. of irradiated element in plant} \times 100}{\text{counts/min./mgm. of irradiated element in solution added to soil}}$$

Specific activity is the number of disintegrations per unit time per unit weight of material. Fortunately, each radioisotope has its own characteristic specific activity which distinguishes it from other isotopes.

TREATMENTS

Pot Culture Procedures

The 4 soils studied were added to glazed pots in amounts of 1 kilogram on an air-dry weight basis. The extracted oat residues were thoroughly mixed with the soils. Water was added to the soils until they approached about 60 per cent of the field-water-holding capacity. Radiocalcium or radiostrontium solutions in correct proportions were added to the water that moistened the soils. A sample from each radioactive solution was saved and used as the standard solution for radioactivity measurements. The soils, residues and the radioelements were mixed thoroughly by rolling on paper. Each treatment was set up in duplicate. The pots were seeded with Early Pak tomatoes (*Lycopersicon esculentum*). Vermiculite was placed on the soil surface to keep it moist and help germination.

The radiocalcium experiment was cropped two successive times at 10 and 8 week intervals. After the first cropping, the roots of the tomatoes in the pots were thrown out and the soils were replanted with tomatoes. The radiostrontium experiment was cropped once after the first 10 week-growth period.

Nitrogen in the form of ammonium nitrate and phosphorus in the form of potassium dihydrogen phosphate was added to all pots for the purpose of eliminating nitrogen and phosphorus as limiting elements in the decomposition of the added oat residue.

The plants were cut at ground level and washed thoroughly in distilled water to remove adhering soil particles which may have been contaminated with radioactive element.

Pot Culture Treatments

In the first experiment, the four soils were treated with 0, 4, or 10 tons of extracted oat residue per acre six-inches and supplied with irradiated calcium to give a concentration of 40 p.p.m. of added calcium.

In the second experiment, the soils also were treated with 0, 4, or 10 tons of extracted oat residue per acre six-inches but were supplied with irradiated strontium to give a concentration of 40 p.p.m. or 100 p.p.m. of the element.

The check pots that were controls for both experiments received only 0, 4, or 10 tons of extracted oat residue.

The detailed treatments used in these investigations are indicated in Table 2.

TABLE 2. RATE OF APPLICATION OF CROP RESIDUES, RADIOACTIVE CALCIUM AND STRONTIUM, AND FERTILIZERS TO SOILS USED IN THE GREENHOUSE.

Soil Treatment	Rate of Residue added	Rate of Radio-element added	Nitrogen added as NH_4NO_3	Phosphorus added as KH_2PO_4
	Tons/A-6"	p.p.m.	lbs.N/A-6"	lbs.P_2O_5/A-6"
Calcium Experiment - 1st cropping				
Mohave	0;4;10	40	100	100
Laveen	0;4;10	40	100	100
Tucson	0;4;10	40	100	100
Pima	0;4;10	40	100	100
Calcium Experiment - 2nd cropping				
Mohave	No additional material added	No additional material added	200	200
Laveen			200	200
Tucson			200	200
Pima			200	200
Strontium Experiment				
Mohave	0;4;10	No additional material added	100	100
Laveen	0;4;10		100	100
Tucson	0;4;10		100	100
Pima	0;4;10		100	100
Control Pots - 1st cropping				
Mohave	0;4;10	No additional material added	100	100
Laveen	0;4;10		100	100
Tucson	0;4;10		100	100
Pima	0;4;10		100	100
Control Pots - 2nd cropping				
Mohave	No additional material added	No additional material added	200	200
Laveen			200	200
Tucson			200	200
Pima			200	200

TABLE 3. PLANTING AND HARVESTING DATES OF THE TOMATOES.

Soil Treatment	Planting Date	Harvesting Date
Calcium Experiment		
first cropping	12-12-55	2-21-56
second cropping	3-10-56	5-9-56
Strontium Experiment	12-12-55	2-21-56
Control Pots		
first cropping	12-12-56	2-21-56
second cropping	3-10-56	5-9-56

RESULTS

Influence of Added Extracted Oat Straw and Calcium on Tomato Top Yields of Four Different Soils

First Cropping -- There was a direct correlation between the yield of tomato tops and the rate of application of calcium and extracted oat straw, Figure 1. If the straw application is held constant, the addition of calcium increased the yield of the tomato tops. However, the tomato top yield decreased with increasing residue application. In all cases, the yield of the untreated soil was greater than those receiving 4 or 10 tons of straw. Pima clay loam supported the highest yields followed by Mohave sandy clay loam, Tucson sandy loam, and Laveen sandy loam, Table 4.

Second Cropping -- The residual effect of the calcium and decomposing straw residue was measured by a succeeding tomato crop. The yield of tomato tops for the 4-ton application of straw was greater than that of the no residue and the 10-ton application, Figure 2. This indicated that the residue from the 4-ton application had decomposed sufficiently to allow nutrients immobilized by microbial growth now to become available for plant use. Pima clay loam had the highest yield of tomato tops followed by Tucson sandy loam, Laveen sandy loam, and Mohave sandy clay loam respectively, Table 5.

Influence of Added Extracted Oat Straw and Strontium on Tomato Top Yields of Four Different Soils

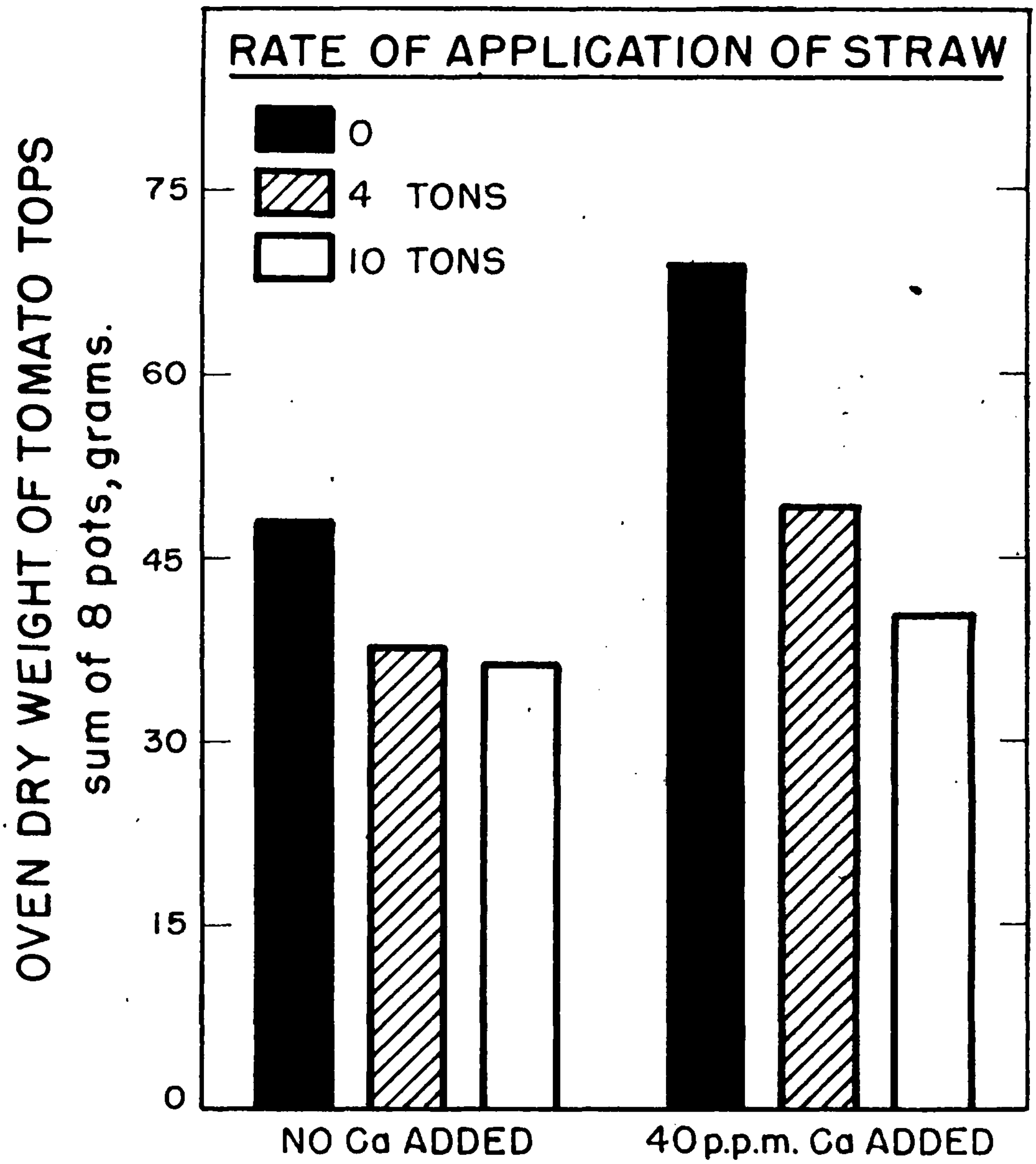

FIGURE 1. INFLUENCE OF ADDED EXTRACTED OAT STRAW AND CALCIUM ON DRY WEIGHT OF TOMATO TOPS (SUM OF TWO REPLICATES FROM FOUR DIFFERENT SOILS, FIRST CROP).

TABLE 4. THE INFLUENCE OF CALCIUM AND EXTRACTED OAT STRAW ADDED TO FOUR DIFFERENT SOILS ON YIELD AND THE UPTAKE OF CALCIUM BY TOMATO TOPS, FIRST CROPPING.

Soil	Straw Added Tons/A	Ca^{45} Added p.p.m.	Yield of* Tomato Tops gm/pot	Total Ca mgm/pot	Calcium per cent	Ca/Ca^{45}**	"A" Value p.p.m.	Ca in plant derived from added source per cent
Mohave	0	0	3.90	63.21	1.61	-	-	-
sandy	4	0	2.15	41.85	1.94	-	-	-
clay	10	0	1.66	39.11	2.35	-	-	-
loam	0	40	6.30	110.80	1.75	195.4	7,164	1.57
	4	40	2.65	41.48	1.56	169.3	6,170	0.68
	10	40	2.69	35.99	1.33	137.3	5,107	0.72
Laveen	0	0	3.56	58.34	1.63	-	-	-
sandy	4	0	2.05	35.68	1.73	-	-	-
loam	10	0	1.44	23.15	1.59	-	-	-
	0	40	5.33	40.34	0.75	121.1	5,208	0.79
	4	40	3.75	33.53	0.89	75.0	3,188	1.06
	10	40	2.44	27.74	1.13	78.8	3,458	0.83
Tucson	0	0	5.13	76.85	1.49	-	-	-
sandy	4	0	2.23	30.85	1.38	-	-	-
loam	10	0	1.98	27.37	1.38	-	-	-
	0	40	6.33	66.86	1.05	149.9	6,958	1.06
	4	40	1.95	28.99	1.48	77.5	3,458	0.89
	10	40	0.93	23.11	2.47	111.6	5,208	0.49
Pima	0	0	11.61	134.49	1.16	-	-	-
clay	4	0	12.03	159.11	1.32	-	-	-
loam	10	0	13.27	214.68	1.61	-	-	-
	0	40	16.70	164.69	0.98	1937.5	53,972	0.31
	4	40	16.45	143.03	0.86	1607.0	43,521	0.32
	10	40	14.81	140.38	0.94	1509.4	40,882	0.34

*Each figure represents a mean of 2 pots and is calculated on an oven-dry weight basis.

**Ca/Ca^{45} represents the ratio between the total calcium in the pot and the calcium found in the pot that is derived from the added source.

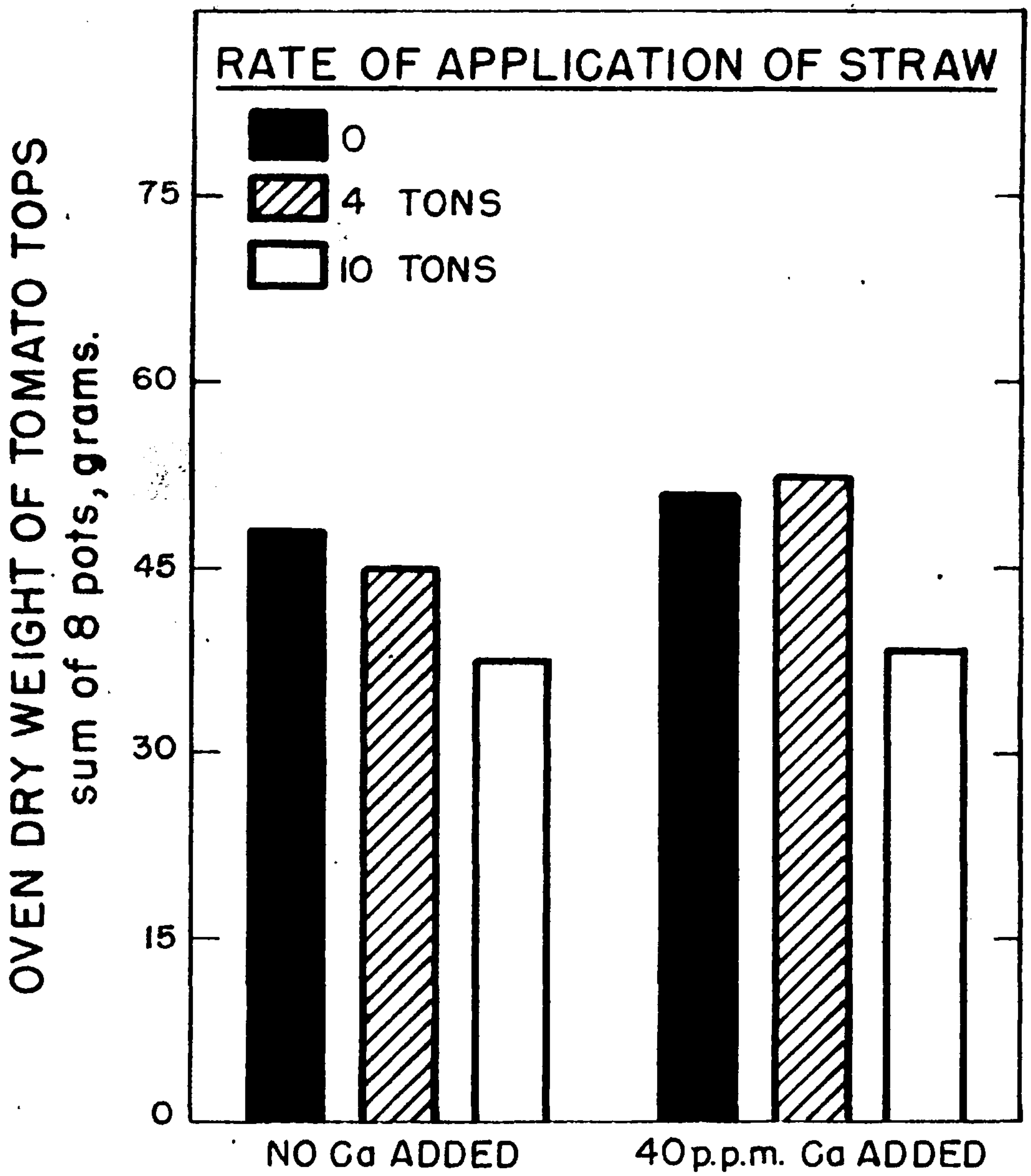

FIGURE 2. INFLUENCE OF ADDED EXTRACTED OAT STRAW AND CALCIUM ON DRY WEIGHT OF TOMATO TOPS (SUM OF TWO REPLICATES FROM FOUR DIFFERENT SOILS, SECOND CROP).

TABLE 5. THE INFLUENCE OF CALCIUM AND EXTRACTED OAT STRAW ADDED TO FOUR DIFFERENT SOILS ON YIELD AND THE UPTAKE OF CALCIUM BY TOMATO TOPS, SECOND CROPPING.

Soil	Straw Added Tons/A	Ca^{45} Added p.p.m.	Yield of Tomato Tops* gm/pot	Total Ca mgm/pot	Calcium per cent	Ca/Ca^{45}**	"A" Value p.p.m.	Ca in plant Derived From Added Source per cent
Mohave	0	0	4.30	57.00	1.32	-	-	-
sandy	4	0	3.41	49.25	1.44	-	-	-
clay	10	0	2.90	48.37	1.66	-	-	-
loam	0	40	5.23	64.50	1.23	139.3	4,639	1.28
	4	40	4.59	64.50	1.40	178.1	6,390	1.00
	10	40	4.10	53.00	1.29	179.6	6,509	0.81
Laveen	0	0	5.40	83.75	1.55	-	-	-
sandy	4	0	3.82	67.00	1.75	-	-	-
loam	10	0	2.92	52.87	1.80	-	-	-
	0	40	6.22	86.00	1.38	124.8	5,208	1.64
	4	40	5.79	91.50	1.57	137.3	5,791	1.58
	10	40	3.29	52.81	1.60	125.4	5,274	1.00
Tucson	0	0	5.82	72.62	1.24	-	-	-
sandy	4	0	5.70	72.00	1.26	-	-	-
loam	10	0	3.83	39.50	1.02	-	-	-
	0	40	5.60	71.87	1.28	203.0	8,529	0.84
	4	40	6.49	100.68	1.55	225.2	9,503	1.06
	10	40	2.77	48.75	1.75	183.9	7,735	0.63
Pima	0	0	8.55	93.87	1.09	-	-	-
clay	4	0	9.88	120.21	1.21	-	-	-
loam	10	0	9.18	116.87	1.27	-	-	-
	0	40	8.74	102.49	1.17	906.9	26,973	0.41
	4	40	9.51	106.25	1.11	863.8	24,518	0.45
	10	40	9.13	112.81	1.23	956.0	26,973	0.43

*Each figure represents a mean of 2 pots and is calculated on an oven-dry weight basis.

**Ca/Ca^{45} represents the ratio between the total calcium in the pot and the calcium found in the pot that is derived from the added source.

Mohave sandy clay loam and Pima clay loam -- If the strontium application is kept constant, increasing the rate of the application of the residue decreased the yield of tomato tops, Figure 3. There was a significant decrease in yield of tomato tops between the no residue and the 4 and 10-ton rate of applications as a result of adding strontium. On the other hand, there was no significant effect of strontium on yields treatments of 4 and 10-tons of straw. There was no significant difference in yields of tomato tops when strontium was omitted as a treatment. Pima clay loam supported higher yields than Mohave sandy clay loam, Table 6.

Laveen and Tucson sandy loam -- There was a direct correlation between the yield of tomato tops and the application of strontium to the extracted oat straw treatments. If the strontium application is kept constant, the yield of tomato tops decreased as the amount of the straw added to the soil was increased, Figure 4. Tucson sandy loam supported higher yields than Laveen sandy loam, Table 6.

Influence of Added Extracted Oat Straw and Calcium on the Total Calcium Uptake and the Ca/Ca^{45} Ratio of Tomato Tops

First Cropping -- The soils with the highest amounts of exchangeable calcium also had the highest total calcium uptake, Table 4. The soils varied in exchangeable calcium from 5 m.e./100 gm. to 30 m.e./100 gm. A correlation coefficient of 0.982 was determined between the exchangeable

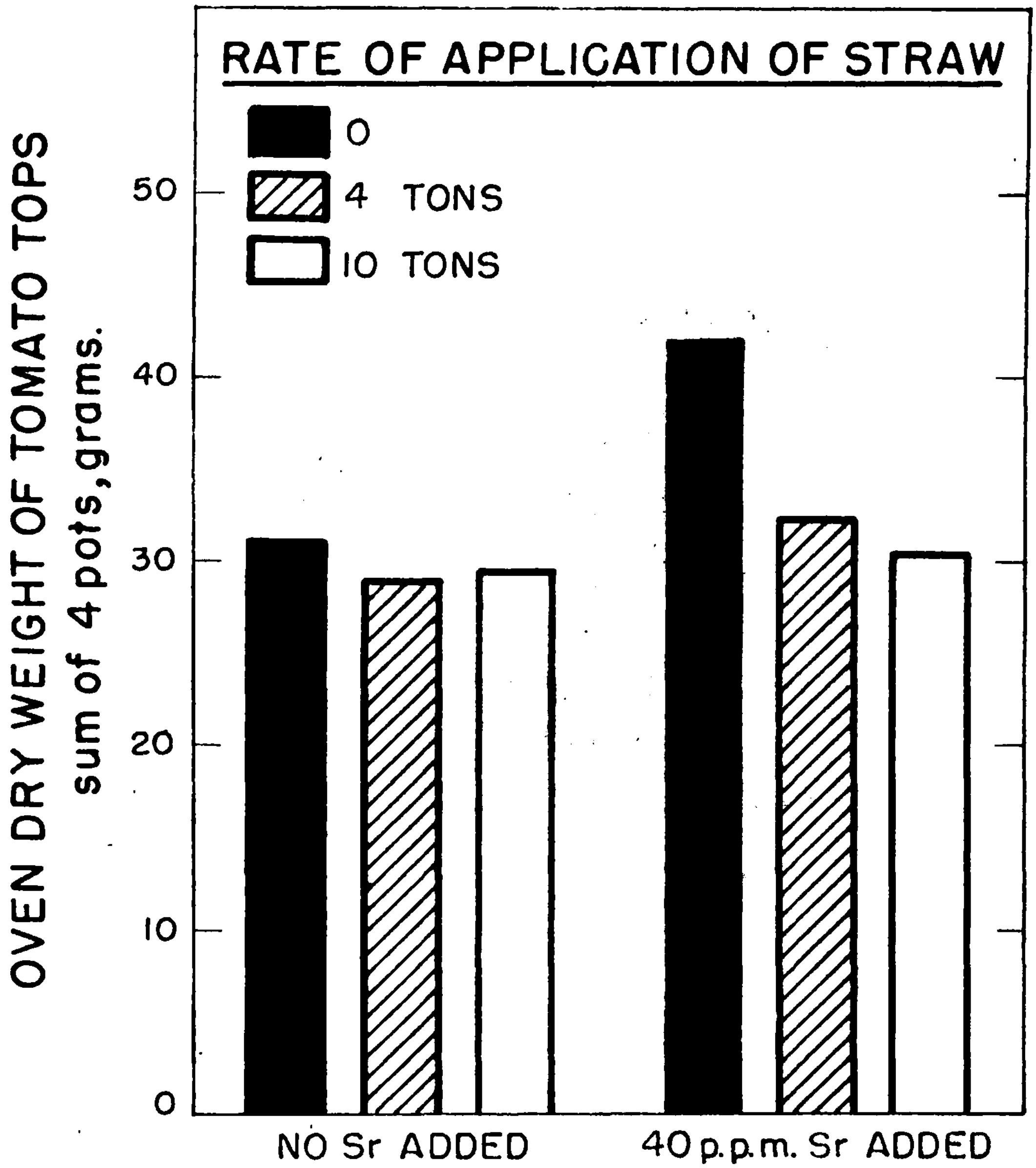

FIGURE 3. INFLUENCE OF ADDED EXTRACTED OAT STRAW AND STRONTIUM ON DRY WEIGHT OF TOMATO TOPS (SUM OF TWO REPLICATES FROM TWO DIFFERENT SOILS).

TABLE 6. THE INFLUENCE OF STRONTIUM AND EXTRACTED OAT STRAW ADDED TO FOUR DIFFERENT SOILS ON THE YIELD AND THE UPTAKE OF CALCIUM AND STRONTIUM BY TOMATO TOPS.

Soil	Straw Added	Sr^{89} Added	Yield of Tomato Tops*	Total Ca	Ca/Sr^{89}**	Total Sr	"A" Value	Sr in plant Derived From Added Source
	Tons/A	p.p.m.	gm/pot	mgm/pot		mgm/pot	p.p.m.	per cent
Mohave	0	0	3.90	63.21	-	-	-	-
sandy	4	0	2.15	41.85	-	-	-	-
clay	10	0	1.66	39.11	-	-	-	-
loam	0	40	4.54	69.42	76.9	0.90	2,996	2.50
	4	40	2.22	47.30	104.4	0.45	3,996	1.25
	10	40	1.91	39.22	153.2	0.25	5,996	0.71
Laveen	0	0	3.56	58.34	-	-	-	-
sandy	4	0	2.05	35.68	-	-	-	-
loam	10	0	1.44	23.15	-	-	-	-
	0	100	5.08	81.14	43.5	1.86	4,667	1.77
	4	100	2.55	43.35	36.6	1.18	3,933	1.12
	10	100	1.95	36.49	37.8	0.96	4,095	0.91
Tucson	0	0	5.13	76.85	-	-	-	-
sandy	4	0	2.23	30.85	-	-	-	-
loam	10	0	1.98	27.37	-	-	-	-
	0	100	6.04	92.27	41.5	2.22	4,460	2.11
	4	100	2.32	35.34	38.1	0.92	4,095	0.88
	10	100	1.99	33.49	59.9	0.55	6,457	0.53
Pima	0	0	11.61	134.49	-	-	-	-
clay	4	0	12.03	159.11	-	-	-	-
loam	10	0	13.27	214.68	-	-	-	-
	0	40	16.59	164.13	138.6	0.65	6,747	2.42
	4	40	13.96	139.63	338.9	0.41	8,997	1.52
	10	40	13.50	105.34	272.1	0.38	8,997	1.43

*Each figure represents a mean of 2 pots and is calculated on an oven-dry weight basis.

**Ca/Sr^{89} represents the ratio between the total calcium in the pot and the strontium found in the pot that is derived from the added source.

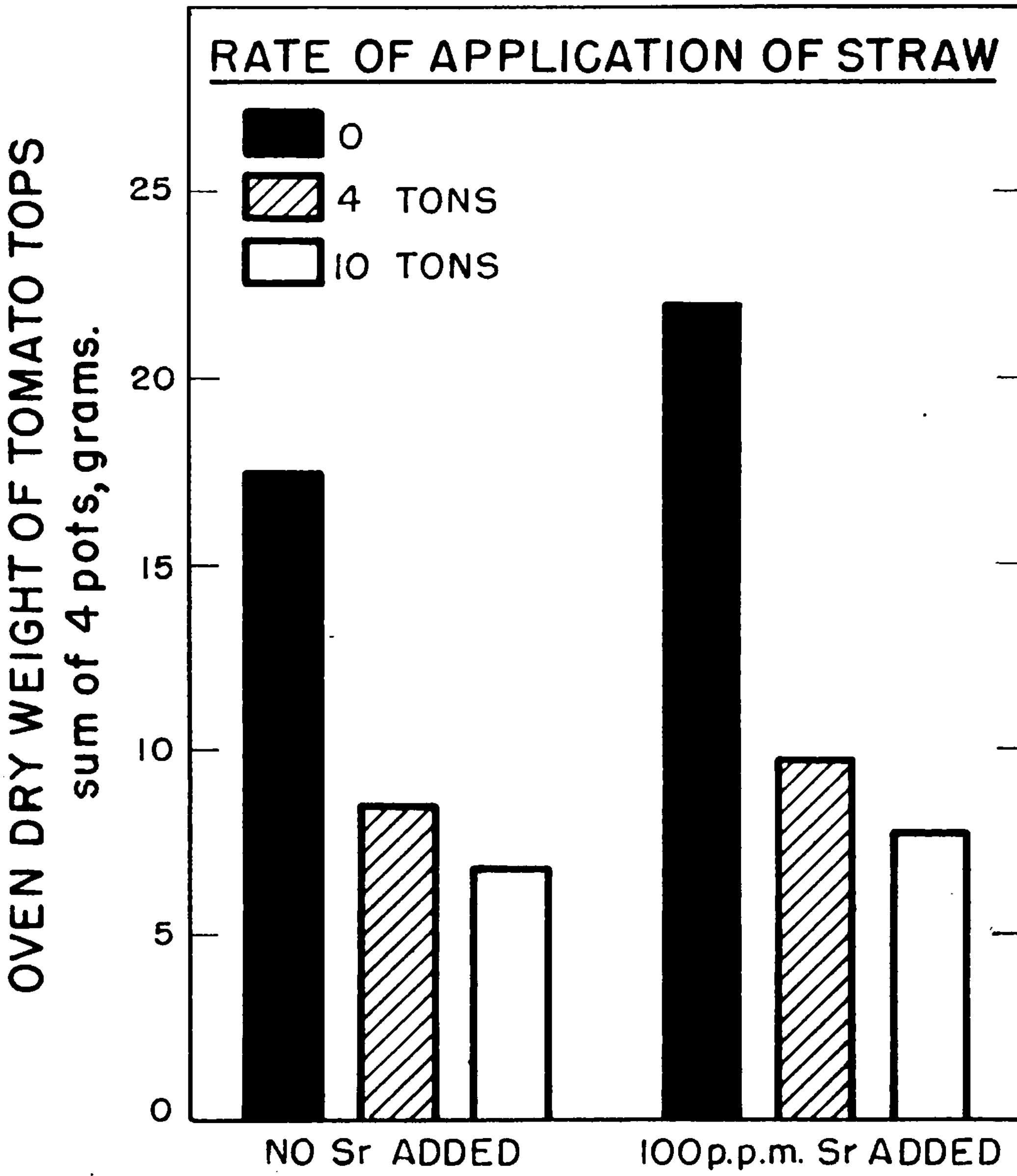

FIGURE 4. INFLUENCE OF ADDED EXTRACTED OAT STRAW AND STRONTIUM ON DRY WEIGHT OF TOMATO TOPS (SUM OF TWO REPLICATES FROM TWO DIFFERENT SOILS).

calcium of the soil and the total calcium taken up when irradiated calcium was added to the soil to give a concentration of 40 p.p.m. The correlation was significant at the 5 per cent level, Figure 5. When 4 or 10-tons of residue and Ca^{45} was added to the soil the correlation coefficient was 0.946 which can be considered significant at the 5 per cent level, Figures 6 and 7.

All three regression lines are plotted in Figure 8. There was no significant difference in the slope of the lines for the three treatments. However, if the exchangeable calcium is kept constant, increasing the amount of residue added to the soil decreased the total calcium taken up.

The (total) Ca/Ca^{45} (added) ratio of the plants increased as the exchangeable calcium of the soil increased, Table 4. Pima clay loam had the highest ratio followed by Mohave sandy clay loam, Tucson sandy loam and Laveen sandy loam, respectively. The ratio tends to decrease as the residue application increased.

Second Cropping -- In general the total calcium taken up decreased with increasing rate of residue application. The exception was with tomato plants grown on Pima clay loam which increased in total calcium uptake on addition of crop residues. There was no correlation* between the total calcium taken up from all sources in the soil for the second cropping.

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*No correlation detected at the 5 per cent level.

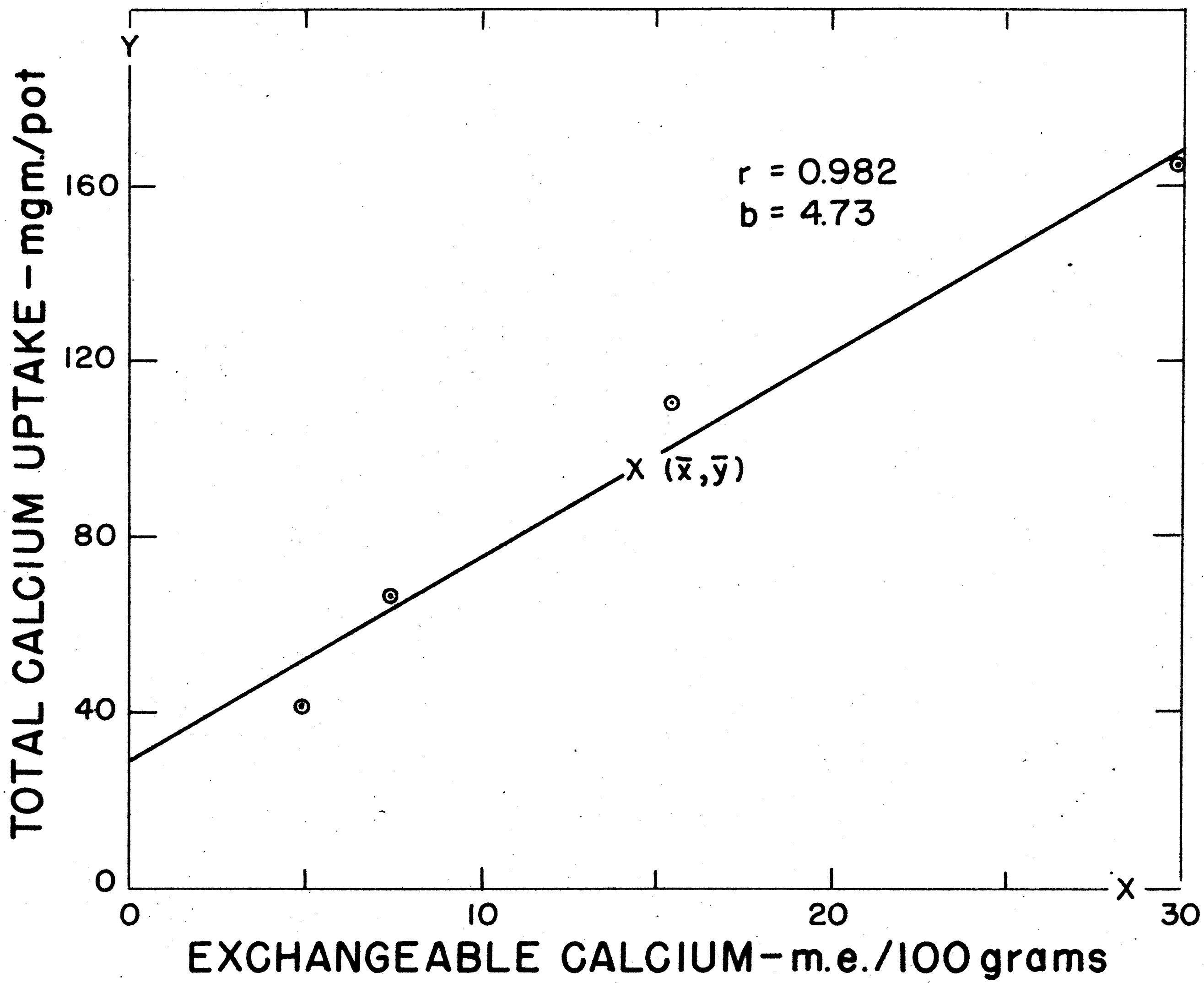

FIGURE 5. RELATIONSHIP BETWEEN THE TOTAL CALCIUM UPTAKE AND EXCHANGEABLE CALCIUM CONTENT OF FOUR DIFFERENT SOILS WHEN CALCIUM WAS ADDED TO GIVE A CONCENTRATION OF 40 p.p.m. TO THE SOILS, FIRST CROP.

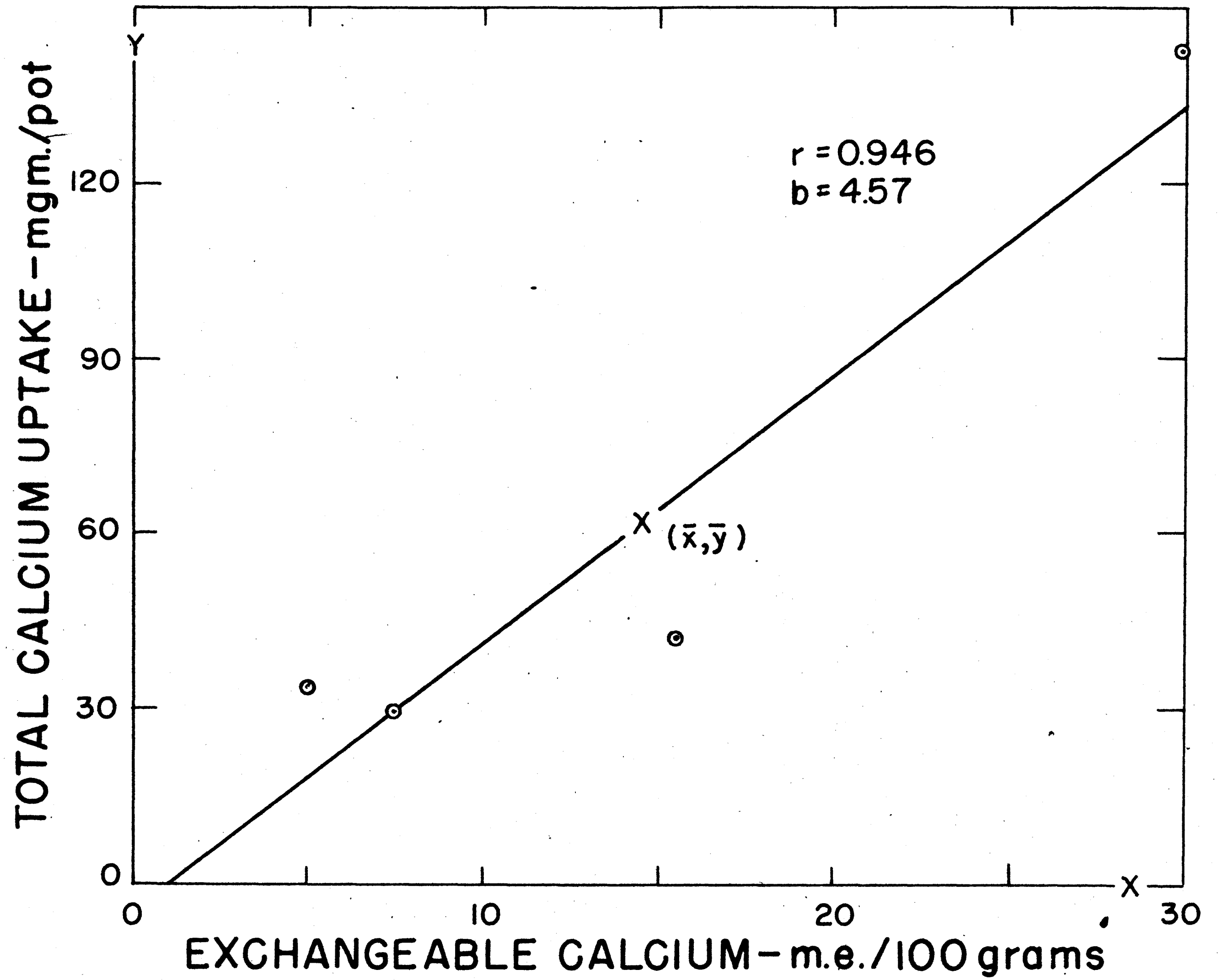

FIGURE 6. RELATIONSHIP BETWEEN THE TOTAL CALCIUM UPTAKE AND EXCHANGEABLE CALCIUM CONTENT OF FOUR DIFFERENT SOILS WHEN CALCIUM WAS ADDED TO GIVE A CONCENTION OF 40 p.p.m. AND FOUR TONS/ACRE OF EXTRACTED OAT STRAW WAS ADDED, FIRST CROP.

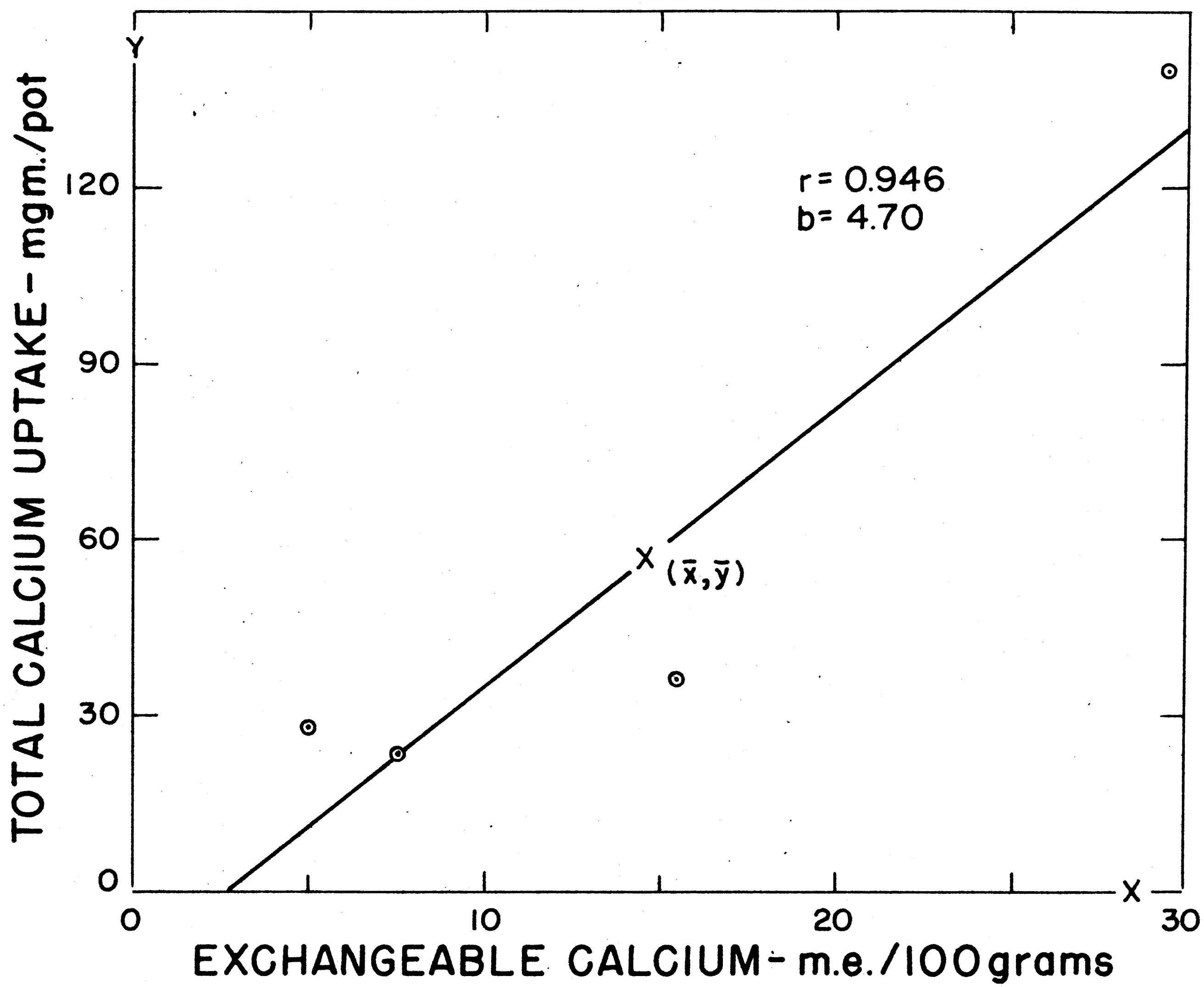

FIGURE 7. RELATIONSHIP BETWEEN THE TOTAL CALCIUM UPTAKE AND EXCHANGEABLE CALCIUM CONTENT OF FOUR DIFFERENT SOILS WHEN CALCIUM WAS ADDED TO GIVE A CONCENTRATION OF 40 p.p.m. AND TEN TONS/ACRE OF EXTRACTED OAT STRAW WAS ADDED, FIRST CROP.

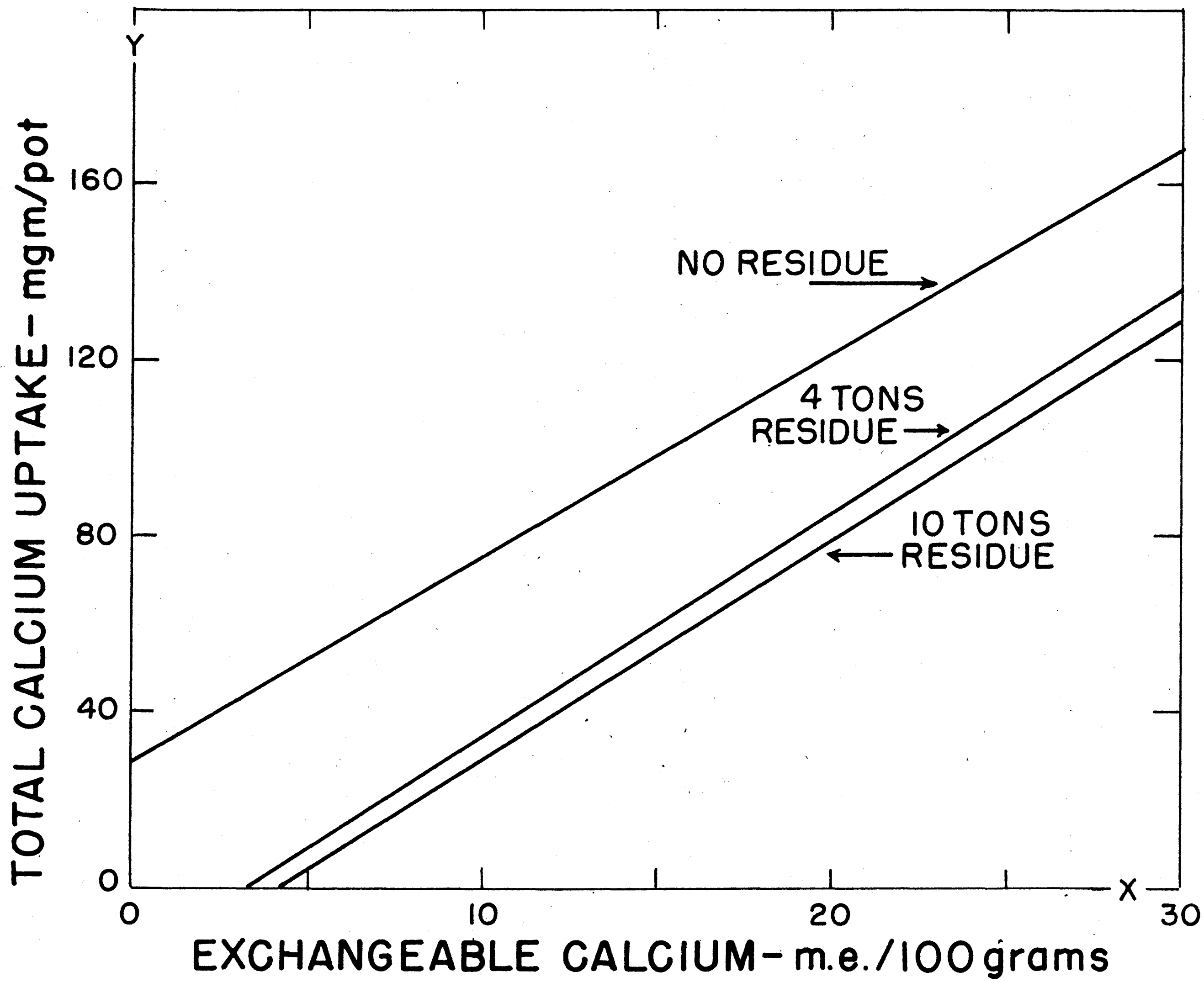

FIGURE 8. RELATIONSHIP BETWEEN THE TOTAL CALCIUM UPTAKE AND EXCHANGEABLE CALCIUM OF FOUR DIFFERENT SOILS WHEN CALCIUM WAS ADDED TO GIVE A CONCENTRATION OF 40 p.p.m. AND EXTRACTED OAT STRAW WAS ADDED, FIRST CROP.

Influence of Added Extracted Oat Straw and Strontium on the Total Calcium and Strontium Taken Up and the Ca/Sr^{89} Ratio of Tomato Tops

Mohave sandy clay loam and Pima clay loam -- The total amount of calcium taken up decreased as the rate of application of residue increased except for the Pima control plants. Tomato tops from the Pima clay loam had a higher calcium uptake than those from Mohave sandy clay loam for corresponding treatments.

The total strontium added taken up decreased with increasing rate of residue application. Tomato plants grown on Mohave sandy clay loam had a higher strontium uptake than those grown on Pima clay loam for corresponding treatments. This data agrees with Fuller and Flocker (15) who stated that the strontium uptake by a plant is an inverse function of the exchangeable calcium of the soil.

The (total) Ca/Sr^{89} (added, irradiated Sr) ratio increased directly as the rate of application of straw increased. Tomato tops from the Pima clay loam had a higher Ca/Sr^{89} ratio than those from Mohave sandy clay loam for corresponding treatments.

Laveen and Tucson sandy loam -- The total amount of calcium taken up decreased with an increase in the rate of application of residue. In general plants grown on Tucson sandy loam had a higher calcium content than those on Laveen sandy loam for corresponding treatments.

The total amount of strontium taken up decreased as the rate of application of residue increased. In general, plants grown on Laveen sandy loam took up more strontium than those grown on Tucson sandy loam.

There was no consistent trend in the Ca/Sr^{89} ratio of plants with respect to the rate of application of residue.

Influence of Added Extracted Oat Straw and Calcium on the "A" Value of Four Different Soils

First Cropping -- The soils with the highest amounts of exchangeable calcium also had the highest "A" values (available calcium) Table 4. A correlation coefficient of 0.930 was determined between the exchangeable calcium of the soil and the "A" value when irradiated calcium was added to the soil to give a concentration of 40 p.p.m. This value can be considered significant at the 5 per cent level, Figure 9. When 4 or 10 tons of residue was added to the soil in addition to calcium, the correlation coefficient was 0.930 and 0.943 respectively, Figures 10 and 11.

All three regression lines are plotted in Figure 12. There was no significant difference in the slopes of the lines for the three treatments. However, if the exchangeable calcium is kept constant, increasing the amount of residue added to the soil decreased the "A" value.

Second Cropping -- There was no correlation between the "A" value and the exchangeable calcium of the soil. However

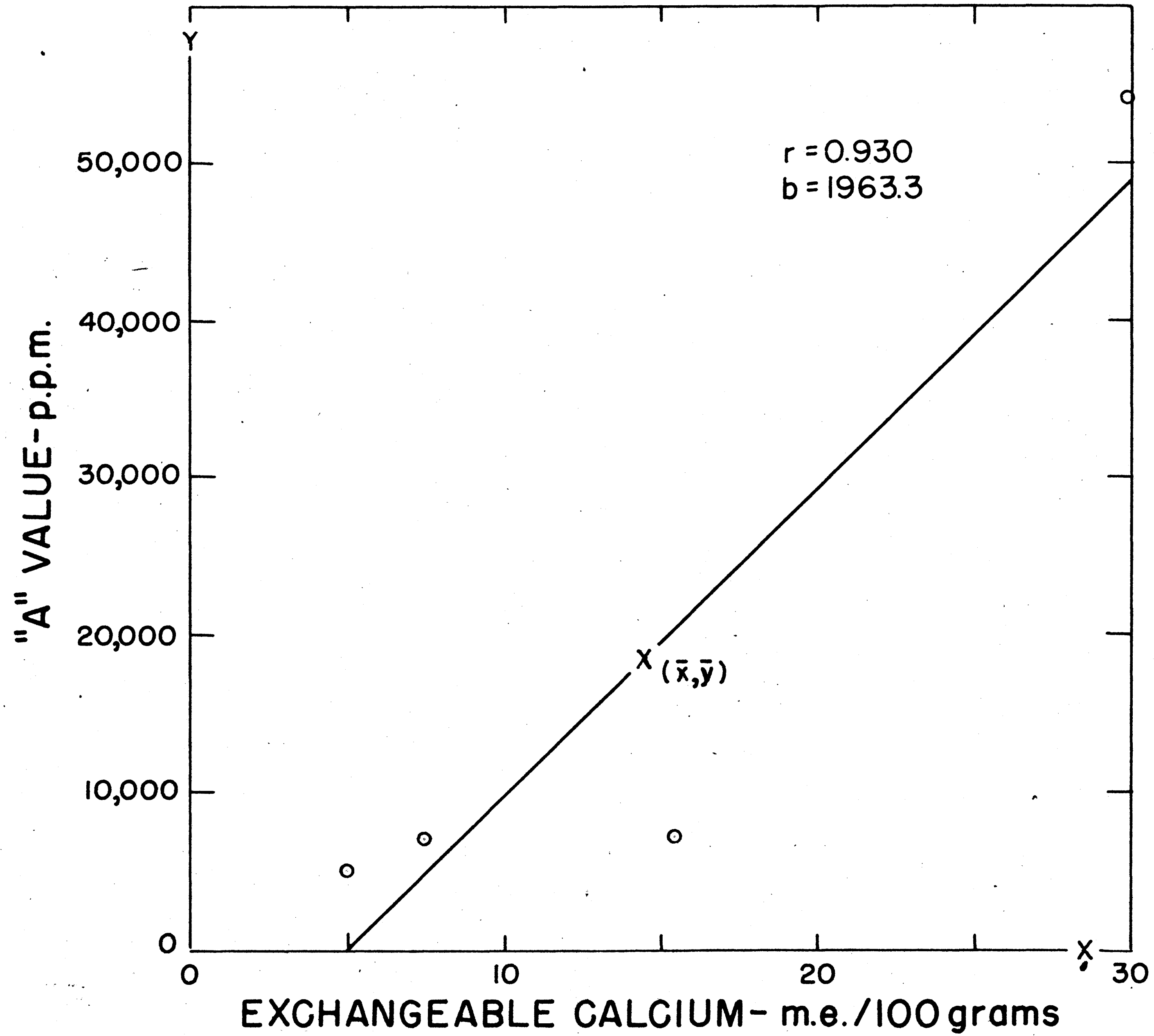

FIGURE 9. RELATIONSHIP BETWEEN THE "A" VALUE AND EXCHANGEABLE CALCIUM CONTENT OF FOUR DIFFERENT SOILS, FIRST CROP.

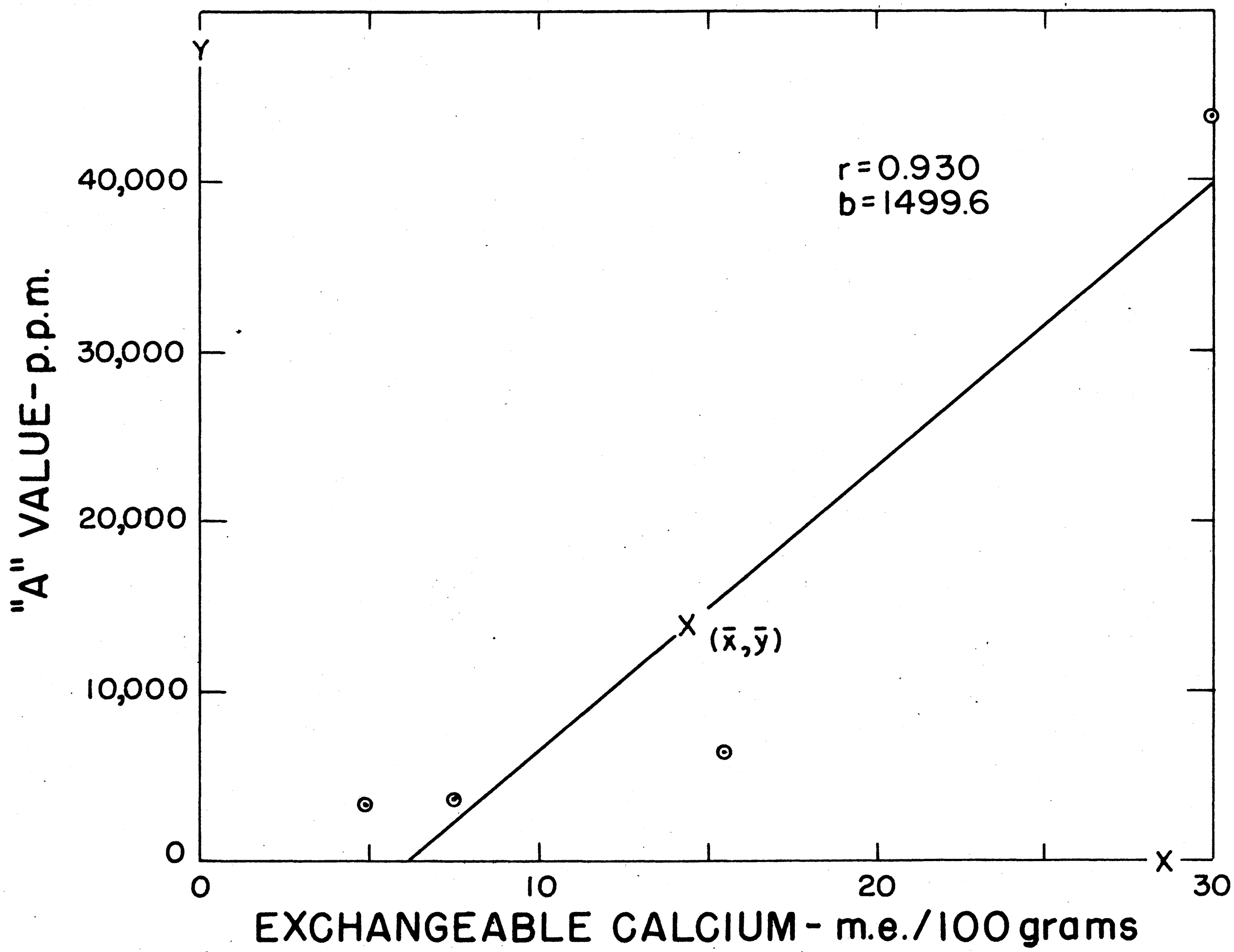

FIGURE 10. RELATIONSHIP BETWEEN THE "A" VALUE AND EXCHANGEABLE CALCIUM CONTENT OF FOUR DIFFERENT SOILS WHEN FOUR TONS OF EXTRACTED OAT STRAW WAS ADDED TO THE SOILS, FIRST CROP.

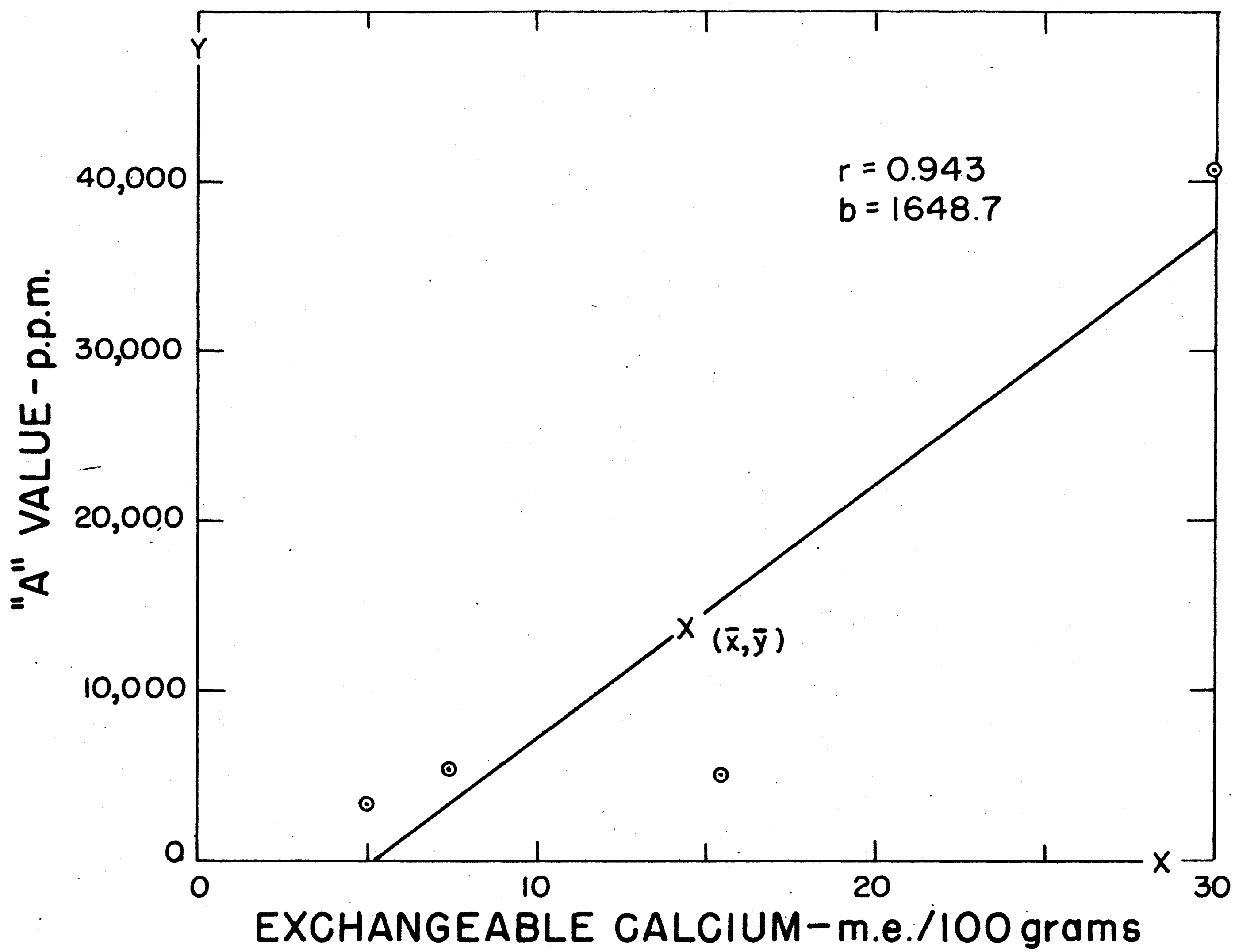

FIGURE 11. RELATIONSHIP BETWEEN THE "A" VALUE AND EXCHANGEABLE CALCIUM CONTENT OF FOUR DIFFERENT SOILS WHEN TEN TONS OF EXTRACTED OAT STRAW WAS ADDED TO THE SOILS, FIRST CROP.

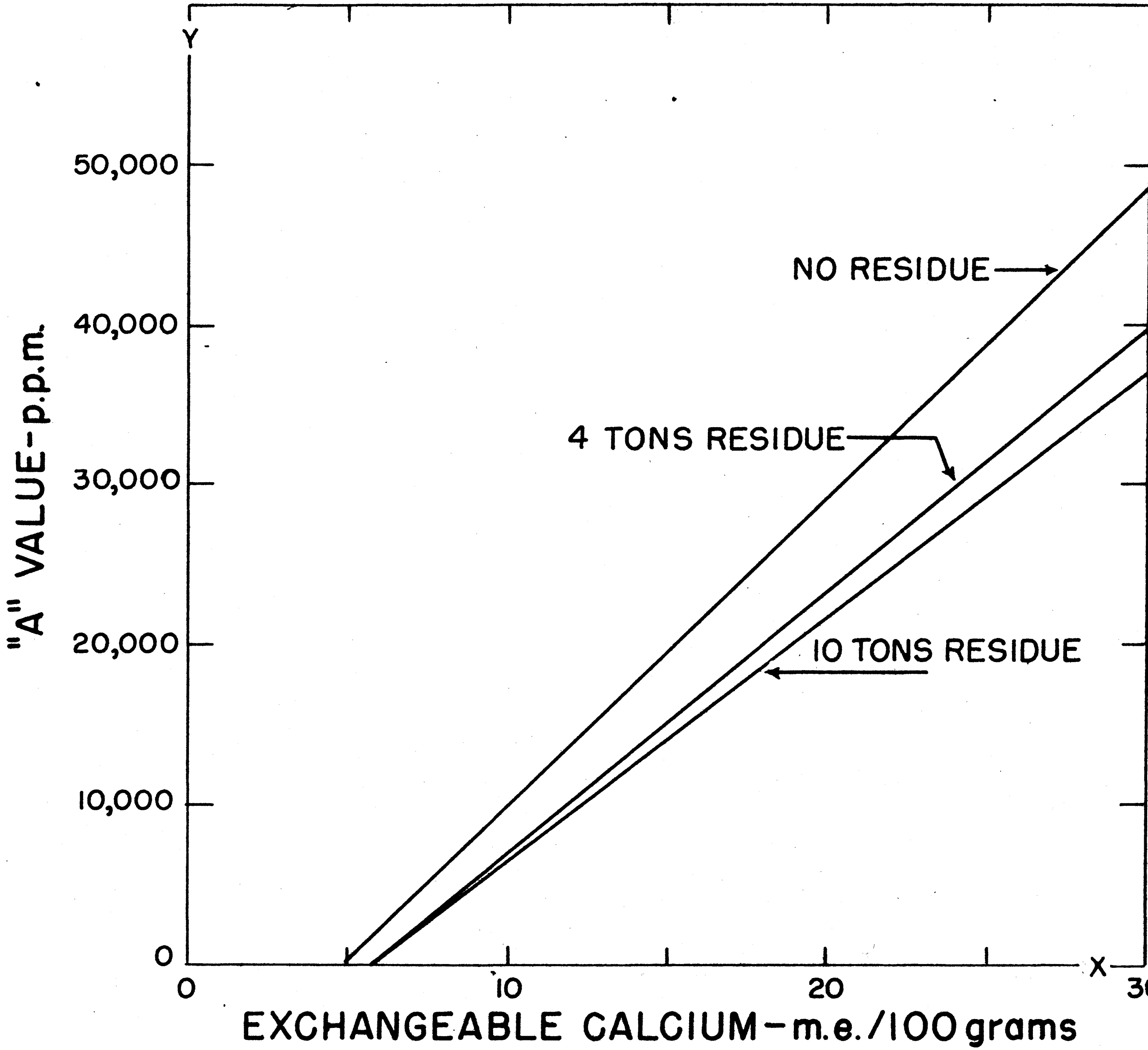

FIGURE 12. RELATIONSHIP BETWEEN THE "A" VALUE AND EXCHANGEABLE CALCIUM ON FOUR DIFFERENT SOILS WHEN EXTRACTED OAT STRAW WAS ADDED TO THE SOILS AT THREE DIFFERENT RATES, FIRST CROP.

the 4-ton residue application had a higher "A" value than the no residue application, except for plants in Pima clay loam where the "A" value decreased.

Influence of Added Extracted Oat Straw and Strontium on the "A" Value of Four Different Soils

Mohave sandy clay loam and Pima clay loam -- The "A" value (available calcium) increased as the amount of residue application increased. Pima clay loam, which has a higher amount of exchangeable calcium on the exchange complex than Mohave sandy clay loam, also had a higher "A" value.

Laveen and Tucson sandy loam -- The "A" value for both soils were about the same for the no residue application. The "A" value for both soils at the 4-ton residue application decreased below that of soil alone. However, the "A" value for soils given 10 tons of residue increased above that of soils given the 4-ton rate.

DISCUSSION

The object of this investigation was to study the influence of extracted straw added to calcareous soils on the uptake of added soluble Ca^{45} and Sr^{89} by tomato plants. The results indicate that the oat straw extracted to remove calcium decreased the yield and nutrient uptake by tomato plants. However, calcium and strontium increased the yield and nutrient uptake by tomato plants.

The decrease in yield due to the added straw was not proportional to the rate (0, 4 and 10-tons/A) of added residue. The greatest decrease in yield of tomato plants per ton of added straw was at the 4-ton rate of application.

The extracted oat straw was mainly carbonaceous and therefore the C/N and C/P ratios were very high. Although nitrogen and phosphorus was added to all pots for the purpose of eliminating these elements as the limiting elements in the decomposition of the added oat straw, indirect evidence indicates that the soil microorganisms used the added nitrogen and phosphorus in order to decompose the straw. The added nitrogen and phosphorus was immobilized by the microbial population and was not available for plant use. The yield of tomato tops from soils having the 4-ton application in the second cropping of the calcium experiment was greater than the no straw and 10-ton application. This indicates that the straw from the lowest rate of application had decomposed sufficiently to allow the nutrients immobilized by microorganisms during the earlier stage of decomposition to become available for plant growth.

The addition of calcium and strontium increased the yields of tomato tops. Two questions arise from the above statement. Why did strontium which is not essential to plant growth increase the yields of tomato tops and why should the addition of soluble calcium to calcareous soils increase the yields of tomato tops? A possible explanation for the increased yields of tomato tops due to strontium is that the added strontium replaced calcium on the exchange complex and the replaced calcium was then available for plant use. Another possible explanation is that strontium can act as a partial replacement for calcium in certain plant functions. This postulate would be in accordance with Hazelhoff (21).

It is generally assumed that calcium nutrition is not a problem of any consequence in calcareous soils. Flocker and Fuller (10) found that the solubility constant of calcium carbonate in some Arizona soils was very low. They found that the absorption of calcium from calcareous soils was not correlated with the percentage calcium carbonate in arid soils. Calcium uptake however, was proportional to the exchangeable calcium. Laveen sandy loam has a high per cent of calcium carbonate but a low per cent exchangeable calcium. Assuming a low solubility product and low exchangeable calcium, then it would seem logical that Laveen sandy loam should respond to a calcium application. Pima clay loam, Mohave clay loam and Tucson sandy loam are low in calcium carbonate but higher than Laveen sandy loam in exchangeable calcium. A possible explanation for the response of these soils to added calcium is that the tomato plants were deficient in calcium and therefore responded to the calcium treatment.

The added straw decreased the total calcium and strontium uptake. The decrease in calcium and strontium uptake was proportional to the exchangeable calcium content of the soil. There was no correlation between the total calcium and strontium uptake and the total calcium carbonate in the soil.

The added straw decreased the calcium and strontium in the tomato tops derived from the added source but increased the Ca/Ca^{45} and Ca/Sr^{89} ratios. This would indicate that the added oat straw increased the availability of the calcium in the soil to the plant. However, due to the tremendous depression in yield of tomato tops by the added straw, the "A" values were indefinite. Therefore no definite conclusions can be drawn as to the effect of crop residues on the availability of native soil calcium to plant growth.

Another approach to this problem would be to grow radiocalcium tagged wheat in sand and gravel tray cultures and measure the direct influence of tagged wheat straw on the calcium uptake by plants. This may prove more fruitful method for determining the effect of crop residues on the availability of calcium to plants then the one reported in this manuscript.

SUMMARY

1. The influence of decomposing oat straw added to calcareous soils on the uptake by tomato plants of added soluble Ca^{45} and Sr^{89} was studied under greenhouse conditions. Furthermore, the availability of native soil calcium as influenced by the presence of oat straw added to the soil was measured by the "A" value technique. These tests were conducted on Mohave sandy clay loam, Pima clay loam, Tucson sandy loam and Laveen sandy loam. The soils varied in calcium carbonate and exchangeable calcium.

2. The addition of calcium or strontium increased the yield of tomato tops while the addition of oat straw decreased the yield of tomato tops.

3. The residual effect of the calcium and decomposing oat straw was measured by the succeeding tomato crop. The yield of tomato tops for the 4-ton application of straw was greater than that of the no straw and 10-ton application.

4. As the exchangeable calcium of the soil increased the total calcium taken up by the tomato plants, the "A" value, and the (total) Ca/Ca^{45} (added) ratio on the tomato plants increased.

5. The strontium taken up by the tomato plant was an inverse function of the exchangeable calcium of the soil. The (total) Ca/Sr^{89} (added, irradiated Sr) ratio increased directly as the rate of application of straw increased.

6. The amount of total calcium and strontium taken up decreased as the rate of application of straw increased for

both the calcium and the strontium experiments.

7. The "A" values for the calcium experiment decreased as the rate of straw increased. However, in the strontium experiment the "A" values increased as the rate of straw increased for Mohave sandy clay loam and Pima clay loam.

EXPERIMENTAL MATERIAL FOR PHOSPHATE EXPERIMENT

Soils

Pima clay loam, Mohave sandy clay loam and Tucson sandy loam were used in this experiment. They were described and analyzed by Flocker (11). They are presented in Table 1.

The three soils used in this experiment were selected mainly on the basis of native phosphate-supplying power. Pima clay loam is high in available phosphate while Mohave sandy clay loam is very low in available phosphate. Tucson sandy loam is intermediate in available phosphate.

Composition of the Crop Residues

The total phosphorus content of the various wheat residues as measured by the Evelyn Photoelectric Colorimeter were as follows: Straw #1* contained 0.47 per cent phosphorus, straw #2 contained 0.20 per cent phosphorus and straw #3 contained 0.05 per cent phosphorus. The total phosphorus content of extracted (P-free) straw #2 was 0.004 per cent.

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*The straw number indicates the tray from which the straw is derived.

EXPERIMENTAL METHODS

Preparation of Labeled Wheat Residues

Delhi wheat (*Triticum vulgare*) which was used as the mature straw residue was grown in quartz sand and gravel in steel trays (6" x 24" x 48"). The seeds were treated with Orthocide 50* to reduce damp-off damage and planted in rows ¼" deep and ½" wide. A thin layer of vermiculite was placed over the sand surface to help keep the sand moist and to insure good germination.

The trays were subirrigated with a balanced nutrient solution, from which phosphorus had been purposely omitted. When the seedlings reached a height of 4 inches, the trays were supplied with water soluble phosphorus at different concentrations. Two trays were supplied with radiophosphorus in the form of irradiated KH_2PO_4 in amounts of 2.272 grams of P to tray #1 and 0.057 grams of P to tray #3. Tray #2 received 1.550 grams of P in the form of KH_2PO_4. The object of varying the amount of phosphorus was to obtain residues whose phosphorus content ranged from high to low. The tray cultures were subirrigated with nutrient solution about once every 24 hours.

The wheat was harvested when mature. The wheat heads were thrown out and only the straw was kept for experimental use. The straws were dried at approximately 65°C for 48 hour period and then ground to pass a 40-mesh screen.

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*California Spray-Chemical Co. trade name for a fungicide containing 50% captan.

Preparation of Extracted Wheat Straw

Wheat straw ground to pass a 40-mesh screen, was treated with 1 per cent sodium hydroxide under flowing steam in a partially open autoclave for 4 hours. The wheat straw was than washed with water followed by dilute sulfuric acid to remove the sodium hydroxide. The straw was rewashed to remove the sulfuric acid and then dried at 65°C for 48 hours. After drying the straw was screened to break up the lumps.

Preparation of Radioactive Phosphorus Solutions

Radioactive phosphorus solutions were prepared by dissolving irradiated KH_2PO_4 in sufficient distilled water and mixing with liquid phosphoric acid (80 per cent C.P.) in such proportions that the aliquot required for each treatment would be of convenient volume.

Preparation of Phosphorus Solutions

Liquid phosphoric acid (80 per cent C.P.) was dissolved in distilled water in such proportions that the aliquot required for each treatment would be of convenient volume.

Chemical Analysis of Wheat Residue

The total phosphorus for the various wheat residues was determined colorimetrically as molybdivanadophosphoric acid (25).

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

The tomato tops which had been oven dried and finely ground were weighed, ashed and filtered with 1N nitric acid through a Whatman No. 40 filter paper into a 100 ml. volumetric flask. The total phosphorus of the plant material was determined colorimetrically from an aliquot of the solution (25). The amount of radiophosphorus taken up by the plant material was also measured from the acid filtrate. The procedure used was the same as used for measuring radiocalcium and radiostrontium, see page 13.

TREATMENTS

Pot Culture Procedures

The three soils studied were added to glazed pots in amounts of 1 kilogram on an air-dry weight basis. The residues were thoroughly mixed with the soils. Water was added to the soils until they approach 60 per cent of the field-water-holding capacity. Radiophosphorus or non-radioactive phosphorus solutions in correct proportions were added to the water that moistened the soils. A sample of each radioactive residue and radiophosphorus solution was saved and used as the standard solution for radioactivity measurements. The soils, residues and solutions were mixed thoroughly by rolling on paper. Each treatment was set up in duplicate. The pots were seeded with Early Pak tomatoes (*Lycopersicon esculentum*). Vermiculite was placed on the surface of the soil to keep it moist and help germination. The tomatoes were harvested after a 10 week-growth period.

Nitrogen in the form of ammonium nitrate was added to all pots at a rate of 100 pounds N per acre-six inches for the purpose of eliminating nitrogen as the limiting element in the decomposition of the added wheat straw.

Pot Culture Treatments

The first part of the experiment was designed to determine the influence of wheat straw on the availability of native soil phosphate to tomato plants when added to three Arizona soils. The various wheat straws and liquid phosphoric acid were added at the rates of 50 or 100 pounds of P_2O_5 per acre-six inches. Nitrogen in the form of ammonium nitrate was added to all pots at the rate of 100 pounds per acre-six inches. The treatments are indicated in Table 8.

The second part of the experiment was designed to study the influence of wheat straw on the utilization of phosphorus of commercial "liquid" H_3PO_4 by tomato plants when added to two Arizona soils. The H_3PO_4 in solution was added at the rate of 150 pounds P_2O_5 per acre-six inches. Straw 2 was added at the rate of 50 pounds of P_2O_5 per acre-six inches. Extracted (P-free) straw 2 was added to the soil at the same rate as straw 2. The treatments are indicated in Table 9.

TABLE 7. RATES OF P OR P^{32} APPLICATION, DATE OF PLANTING, HARVESTING AND P OR P^{32} INJECTION.

Crop residue	Rate of P or P^{32} Application*	Planting Date	Date of P or P^{32} Injection	Harvesting Date
	gm./tray			
Wheat straw 1	2.272	10/26/55	11/17/55	1/26/56
Wheat straw 2	1.550	10/26/55	11/17/55	1/26/56
Wheat straw 3	0.057	10/26/55	11/17/55	1/26/56

*The phosphorus in straw 1 and 3 were supplied as irradiated KH_2PO_4. The phosphorus in straw 2 was supplied as nonradioactive KH_2PO_4.

TABLE 8. TREATMENTS USED IN THE STUDY OF THE INFLUENCE OF WHEAT STRAW ON THE AVAILABILITY OF NATIVE SOIL PHOSPHATE TO TOMATO PLANTS WHEN ADDED TO THREE ARIZONA SOILS.

Soil treatment	Amount of P_2O_5 added from H_3PO_4	Amount of P_2O_5 added from wheat straw	Amount of straw added
	lbs. P_2O_5/A-6"	lbs. P_2O_5/A-6"	Tons/A
	Mohave clay loam		
none	none	none	none
straw 1	none	100	4.6
straw 2	none	100	12.8
straw 3	none	100	37.4
straw 1 + H_3PO_4	50	50	2.3
straw 3 + H_3PO_4	50	50	18.7
H_3PO_4	100	none	none
	Pima clay loam		
none	none	none	none
straw 1	none	100	4.6
straw 2	none	100	12.8
straw 3	50	50	37.4
straw 1 + H_3PO_4	100	none	2.3
H_3PO_4	100	none	none
	Tucson sandy loam		
none	none	none	none
straw 1	none	100	4.6
straw 1 + H_3PO_4	50	50	2.3
H_3PO_4	100	none	none

TABLE 9. TREATMENTS USED IN THE STUDY OF THE INFLUENCE OF WHEAT STRAW ON THE UTILIZATION OF PHOSPHORUS FROM LIQUID H_3PO_4 BY TOMATO PLANTS WHEN ADDED TO TWO ARIZONA SOILS

Soil Treatment	Amount of P_2O_5 added from H_3PO_4	Amount of P_2O_5 added from wheat straw	Amount of straw added
	lbs. P_2O_5/A-6"	lbs. P_2O_5/A-6"	Tons/A
		Mohave clay loam	
none	none	none	-
H_3PO_4	150	none	-
H_3PO_4 + Straw 2	150	50	6.4
H_3PO_4 + extracted straw 2(P-free)	150	none	6.4
		Pima clay loam	
none	none	none	-
H_3PO_4	150	none	-
H_3PO_4 + Straw 2	150	50	6.4
H_3PO_4 + extracted straw 2(P-free)	150	none	6.4

RESULTS

Influence of Wheat Straw on the Availability of Native Soil Phosphate to Tomato Plants When Added to Three Arizona Soils

Yield -- The yield of tomato tops was significantly higher on Mohave clay loam when the soil received an application of straw 1 having a phosphorus content of 0.47 per cent than when it received no straw or straw containing 0.20 or 0.05 per cent phosphorus, Table 10. The yield of tomato tops also was significantly higher in Mohave clay loam when the soil received a split application of the high phosphate straw and liquid phosphoric acid than when it received no straw or just liquid phosphoric acid. There was no significant difference in yield of tomato tops between the split application of straw (0.47 per cent P) and liquid phosphoric acid or just straw 1. The split application of straw 1 and liquid phosphoric acid had significantly higher tomato top yields than the split application of straw 2 (0.20 per cent P) and liquid phosphoric acid.

Liquid phosphoric acid increased the tomato top yields in all three soils above that of the untreated soils. However, the increase in yield was not significantly higher.

Yields of tomato tops on Pima clay loam were not significantly influenced by the different straws, liquid phosphoric acid or combination of both.

TABLE 10. INFLUENCE OF WHEAT STRAW ON THE UPTAKE OF SOIL PHOSPHATE BY TOMATO PLANTS WHEN ADDED TO THREE ARIZONA SOILS.

Materials added	Amount of straw added*	Yield of tomato tops**	Total P of tomato tops		P derived from added source	
	T./A.	gm./pot	per cent	mgm./pot	per cent	mgm./pot
Mohave sandy clay loam						
none	none	1.52	0.18	2.58	0.0	none
straw 1	4.6	4.16	0.16	7.03	42.3	3.47
straw 2	12.8	1.29	0.19	2.55	-	-
straw 3	37.4	0.42	0.07	0.33	nil	nil
straw 1 + H_3PO_4	2.3	3.76	0.23	8.67	28.4	2.46
straw 3 + H_3PO_4	18.7	1.17	0.10	1.17	nil	nil
H_3PO_4	none	1.84	0.24	4.60	-	-
L.S.D. (0.05)		1.67		2.32		
Pima clay loam						
none	none	6.71	0.24	16.56	0.0	none
straw 1	4.6	8.33	0.21	17.58	13.5	2.38
straw 2	12.8	7.58	0.22	17.00	-	-
straw 1 + H_3PO_4	2.3	7.49	0.25	18.93	9.4	1.58
H_3PO_4	none	7.42	0.27	20.40	-	-
L.S.D. (0.05)		n.s.		2.77		
Tucson sandy loam						
none	none	1.36	0.23	3.19	0.0	none
straw 1	4.6	3.75	0.21	8.08	39.6	3.49
straw 1 + H_3PO_4	2.3	3.75	0.21	8.24	32.6	2.69
H_3PO_4	none	1.79	0.31	5.68	-	-
L.S.D. (0.05)		2.30		3.18		

*The phosphorus in straw 1 and 3 were supplied as irradiated KH_2PO_4. The phosphorus in straw 2 was supplied as nonradioactive KH_2PO_4. The phosphorus in liquid phosphoric acid was nonradioactive.

**Mean of two pots containing 1 kg. of soil. Data are calculated on a dry-weight basis.

An application of the straw having the highest percentage P on Tucson sandy loam increased tomato top yields significantly above the untreated soil. There was no significant difference between the yields of tomato tops due to the application of straw having 0.47 per cent P and the yields due to liquid phosphoric acid or a split application of both.

Total Phosphorus Content of Tomato Tops -- The total phosphorus content of the tomato tops harvested from both Mohave and Pima soils was found to be directly related to the amount of phosphorus in the straw, Table 10. For example, significantly more phosphorus was taken up by the tomato plants grown on Mohave clay loam from straw containing 0.47 than from straw of 0.20 or 0.05 per cent phosphorus. There was no significant difference between tomato plants grown on Pima clay loam that received applications of straw having the highest P content or that having the lowest P content.

Percentage of Phosphorus Derived From Straw -- In all soils, the percentage of phosphorus in the tomato tops derived from the straw having 0.47 per cent P was greater than from the straw and liquid phosphoric acid added as a split application with reference to phosphorus.

Total Phosphorus Uptake -- The total phosphorus taken up by tomato plants was greatest from Pima clay loam followed by Tucson sandy loam and Mohave sandy clay loam.

Influence of Wheat Straw on the Utilization of Phosphorus From Liquid H_3PO_4 by Tomato Plants When Added to Two Arizona Soils

Yield -- The yield of tomato tops on Pima clay loam was not significantly influenced by the straws, liquid phosphoric acid or a combination of both, Table 11. The application of liquid phosphoric and the split application of liquid phosphoric acid and straw 2 (0.20 per cent P) on Mohave clay loam increased the tomato top yields significantly above the untreated soil. The split application of liquid phosphoric acid and extracted straw 2 (0.004 per cent P) was significantly lower than the untreated soil, Table 11.

Total Phosphorus Content of Tomato Tops -- The total phosphorus content of tomato tops on Pima clay loam was not significantly influenced by the straws, liquid phosphoric acid or a combination of both, Table 11. The application of liquid phosphoric acid and the split application of liquid phosphoric acid and the straw having 0.20 per cent P on Mohave clay loam increased the total phosphorus content significantly above the untreated soil. On the other hand the phosphorus content of the test crop receiving liquid phosphoric acid and phosphorus-free straw (extracted) was significantly lower than the untreated soil.

TABLE 11. INFLUENCE OF WHEAT STRAW ON THE UTILIZATION OF PHOSPHORUS FROM LIQUID H_3PO_4 BY TOMATO PLANTS WHEN ADDED TO TWO ARIZONA SOILS.

Materials added	Amount of straw added	Yield of tomato tops*	Total P of tomato tops		P derived from added source	
	T./A	gm./pot	per cent	mgm./pot	per cent	mgm./pot
			Mohave sandy clay loam			
none	none	1.52	0.18	2.58	none	none
H_3PO_4**	none	1.98	0.23	4.73	33.8	1.60
H_3PO_4 + straw 2	12.8	2.62	0.27	7.13	36.7	2.62
H_3PO_4 + straw 2***	12.8	0.09	0.31	0.28	14.2	0.04
L.S.D. (0.05)		0.42		0.80		
			Pima clay loam			
none	none	6.71	0.24	16.56	none	none
H_3PO_4	none	8.26	0.26	21.98	12.5	2.75
H_3PO_4 + straw 2	12.8	8.45	0.25	20.85	10.6	2.27
H_3PO_4 + straw 2***	12.8	7.77	0.25	19.53	14.8	2.89
L.S.D. (0.05)		n.s.		n.s.		

*Mean of two pots containing 1 kg. of soil. Data are calculated on a dry-weight basis.

**Irradiated KH_2PO_4 was mixed with liquid phosphoric acid.

***Phosphate extracted straw 2 (P-free) was added to the soil at the same rate as natural straw 2. Straw 2 originally contained 0.20 per cent phosphorus.

Percentage of Phosphorus Derived From Straw -- The percentage of phosphorus in the tomato tops derived from liquid phosphoric acid on Mohave clay loam was increased by the addition of the straw having 0.20 per cent P and decreased by the addition of extracted straw.

Total Phosphorus Uptake -- The total phosphorus taken up by tomato plants was greater in the Pima clay loam than the Mohave sandy clay loam.

DISCUSSION

Large quantities of organic materials are plowed into the soil to serve as sources of elements essential to plant growth. The phosphorus contained in these organic materials often forms the largest added source of this nutrient element that is available for the following crop.

The use of phosphoric acid in aqueous solution as a source of phosphate fertilizer has increased greatly during recent years. The fertilizer is applied either in irrigation water or injected directly into the soil. A better understanding of the influence of organic materials on the availability of native soil phosphate and the influence of organic material on the utilization of phosphorus from liquid phosphoric acid is a practical problem of importance to the farmer.

In an experiment designed to obtain an answer to these problems, it was found that the yield of tomato tops was significantly higher on a soil that received an application of wheat straw having a phosphorus content of 0.47 per cent than when it received no straw or straw containing 0.20 or 0.05 per cent phosphorus. Moreover the total phosphate content of the tomato tops increased directly as the phosphate content of the wheat straw increased. This data is in agreement with Fuller, et al. (16) who found that the threshold of the phosphorus content of barley straw, above which the element is not wholly immobilized for use in decomposition is about 0.2 per cent. The investigators also found that the percentage phosphorus in the test crop derived from the crop residue added to the soils increased directly as the phosphorus content of the crop residue increased.

Although there was a higher total phosphate content in the tomato tops that received the split application of straw having 0.47 per cent P and liquid phosphoric acid than the same straw added alone, the phosphorus in the tomato top derived from the added straw was less in the split application of straw plus liquid phosphoric acid than the straw alone. No real difference was exhibited between the total phosphate content in the tomato tops that received the split application of straw and liquid phosphoric acid. However no definite conclusion can be drawn on the basis of this single experiment.

The split application of liquid phosphoric acid and straw extracted to remove the P - depressed the yield and total phosphate content of tomato tops on Mohave clay loam below that of the crop from the soil receiving liquid phosphoric acid alone. Moreover, the application of liquid phosphoric acid and extracted straw as a split treatment on Mohave clay loam decreased the phosphate derived from the added liquid phosphoric acid below that of the split treatment of liquid phosphoric acid and the natural straw having 0.20 per cent phosphorus.

The effect of adding phosphorus in combination with extracted wheat straw was to immobilize the phosphorus. Phosphorus in organic material is only temporarily fixed: however, unlike inorganic fixation organic phosphorus eventually may become wholly available for plant use.

Practical significance of the above data may be applied in the field. A farmer should give his "plowed-down" residue time to decompose so that the organic phosphorus might become available for plant utilization or else add sufficient fertilizer phosphorus to overcome the depressive effect of straw on crop yields.

SUMMARY

1. The influence of wheat straw on the availability of native soil phosphate to tomato plants when added to three Arizona soils, was studied under greenhouse conditions. Furthermore, a study was made of the influence of wheat straw on the utilization of phosphorus from liquid phosphoric acid by tomato plants when added to two Arizona soils. These tests were conducted on Mohave sandy clay loam, Tucson sandy loam and Pima clay loam. The soils varied in native phosphate-supplying power and calcium characteristics.

2. The yield of tomato tops was significantly higher on Mohave clay loam when the soil received an application of straw having a phosphorus content of 0.47 per cent than when it received no straw or straw containing 0.20 or 0.05 per cent phosphorus. These straws had no significant effect on yields when added to either Tucson sandy loam or Pima clay loam.

3. The total phosphate content of the tomato tops increased directly as the phosphorus content of the wheat straw increased.

4. The percentage of phosphorus in the tomato tops derived from the straw having 0.47 per cent P was greater than the phosphorus in the tomato tops derived from the split application of the straw and liquid phosphoric acid.

5. The addition of liquid phosphoric acid alone and the split application of liquid phosphoric acid and straw having 0.20 per cent P to Mohave clay loam resulted in an increase in tomato top yields significantly above the untreated soil.

6. The percentage of phosphorus in the tomato tops derived from liquid phosphoric acid on Mohave clay loam was increased by the addition of the straw having 0.20 per cent P and decreased by the addition of the same straw extracted to remove its phosphorus.

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