STRONTIUM-90 ACCUMULATION BY SOME VEGETABLE CROPS[1, 2]

F. HAGHIRI

Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio

The biological significance of strontium-90 in the food chain has been recognized since the advent of nuclear fission. Foliar and root absorption of strontium-90 by plants are two major pathways of strontium–90 entry into man's diet. During nuclear testing foliar contamination with subsequent absorption of this isotope by plants is the predominant pathway. After the cessation of nuclear testing the uptake of radio-strontium from soil through the plant roots becomes increasingly important (Comar and Thompson, 1963).

Since many vegetable crops are consumed by man in raw form, it is of interest to know to what extent various vegetable crops differ in their uptake of strontium-90 when grown in a contaminated soil medium.

It is reported that plant species vary in their absorption of strontium-90 from uniformly contaminated soil (Haghiri and Sayre, 1961; Jones and Haghiri, 1962; and Fuller and Flocker, 1955) and this variation is closely related to the variation in calcium absorption (Vose and Koontz, 1960; Menzel, 1959; and Evans and Decker, 1962). Duckworth and Hawthorn (1960) and Romney et al. (1957) reported that within a plant species different plant organs vary in their strontium-90 accumulation. The concentration of strontium-90 is reported to be the highest in the older leaves (Nishita et al., 1961) while approximately one tenth as much is found in the seeds (Neel et al., 1953).

The objectives of this study were (a) to determine to what extent different vegetable crops differ in their strontium-90 accumulation when grown on an acid Ohio soil contaminated with strontium-90 and (b) to relate the strontium-90 content of plant tissue to the concentrations of major and minor elements found in these plant tissues.

MATERIALS AND METHODS

Ten different vegetable crops, i.e., eggplant, radish, tomato, snapbean, cauliflower, cucumber, hot pepper, sweet pepper, celery, and beet were used in this study. Plants were grown in one-gallon closed-bottom tin cans, lined with polyethylene bags and containing 2.5 kg air-dried Canfield silt loam soil. The soil has a pH of 5.6 with 12.3, 7.4, 1.1, and 0.37 mEq of exchangeable H, Ca, Mg, and K, respectively, per 100 g of soil. Seven weeks after the seeds were planted, surface application (soil) of 10 μc of carrier-free strontium-90 solution in the form of $SrCl_2$ was made. Time of harvest for different crops varied considerably depending on the crop species. Some were harvested at maturity and others at the normal stage of growth for their harvest. With the exception of radish and beet, only the aerial parts of plants were harvested. After the harvest, the aerial parts of plants were separated, dried in a forced-air oven at 70 C, and ground in a micro-Wiley mill to a fine powder. After sufficient time was allowed for strontium-90 to grow into equilibrium with yttrium-90, a 1.00-g oven-dried plant tissue sample was used for strontium-90 assay. Since plant tissue samples were powdery, each sample was treated with 1 ml of lucite in acetone (0.5 g/100 ml) plus an additional amount of acetone to wet the entire sample; then samples were dried and counted

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for beta activity. The activity of strontium-90 in the plant samples was determined by using a Nuclear-Chicago D48 gas-flow detector with Model C210 automatic sample changer.

Plant samples were also assayed for K, P, Ca, Mg, Mn, Fe, B, Cu, Zn, Al, Sr, Mo, Co, Na, SiO_2, and Ba by using Direct Reading, Emission Spectrograph, Jarrell-Ash Compact Atomcounter, Model 66–001. A 0.5-g oven-dried plant tissue sample was ashed at 500 C for 4 hrs. The plant ash was dissolved in 2.5 ml of a buffer solution (HNO_3, Li_2CO_3 with Li as internal standard). Approximately 1 hr after the buffer was added the elements were assayed.

RESULTS AND DISCUSSION

The concentration of strontium-90 (mμc/g dry matter) found in vegetable crops varied considerably depending on the plant species. In general, high strontium-90 concentrations in plants were associated with high Ca, Mg, Sr and Ba contents, and low strontium-90 concentrations were associated with low Ca, Mg, Sr and Ba contents (table 1). Similar results were reported by Evans and Dekker (1962). The correlation coefficients for strontium-90 and Ca (0.85**), strontium-90 and Mg (0.71**), strontium-90 and Sr (0.89**), and strontium-90 and Ba (0.82**) were significant. Such a relationship is to be expected since Ca, Mg, Sr, and Ba are all members of the alkaline earth family.

TABLE 1

*Strontium-90 and alkaline earth contents of various parts of vegetable crops**

Plant material	Sr^{90} mμc/g	Ca mg/g	Mg mg/g	Sr mg/g	Ba ppm	Sr^{90} μc/g Ca
Beet, leaves	105.6	13.0	8.1	40	30	3.79
Beet, petiols	44.8	7.5	6.7	60	45	5.97
Beet, root	7.8	2.2	2.7	16	20	3.54
Cauliflower, leaves	67.6	19.0	2.9	120	37	3.55
Cauliflower, stems	20.5	4.8	3.1	39	22	4.27
Cauliflower, head	2.9	1.2	1.6	2	2	2.41
Celery, leaves	66.9	22.5	4.7	93	22	2.97
Celery, stems	30.8	7.4	3.2	52	15	4.16
Cucumber, leaves	128.1	30.0	6.1	245	58	4.27
Cucumber, stems	121.6	20.0	10.2	195	63	6.08
Cucumber, flower	113.9	16.5	6.4	120	67	6.90
Cucumber, fruit	10.4	1.9	2.2	6	5	5.47
Eggplant**, leaves	84.9	29.5	6.4	145	24	2.87
Eggplant, stems	30.5	7.8	2.8	59	14	3.91
Eggplant, flower	40.5	21.0	5.5	95	5	1.92
Radish, tops	82.2	31.9	5.0	265	68	2.57
Radish, root	63.1	4.4	1.9	50	27	14.34
Snapbean, leaves	107.2	32.5	4.1	230	83	3.29
Snapbean, stems	46.2	8.6	2.9	60	20	5.37
Snapbean, fruit	32.1	4.4	3.1	18	15	7.29
Sweet pepper, leaves	79.3	25.5	5.8	105	24	3.11
Sweet pepper, stems	59.9	11.0	6.2	74	17	5.44
Sweet pepper, fruit	3.4	1.3	1.6	2	1	2.61
Tomato, leaves	105.6	36.0	6.0	200	33	2.93
Tomato, stems	40.1	12.0	6.2	76	20	3.34
Tomato, fruit	0.7	0.6	1.1	1	1	1.16

*Values are average of three replications.
**Eggplant failed to produce fruit.

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*Significant at 5% level.
**Significant at 1% level.

There was a significant relationship between the strontium-90 content and several of the minor elements. High and low strontium-90 activities were associated with high and low Mo, Co, Zn, Al, and Mn contents of plant tissue (table 2). There were significant positive correlations between the strontium-90 and Mo (r=0.82**), strontium-90 and Co (r=0.60**), strontium-90 and Zn (r=0.38*), strontium-90 and Al (r=0.40*), and strontium-90 and Mn (r=0.36*). High correlation coefficient value for Mo may suggest that perhaps Mo could possibly be used as an indicator of strontium-90 content in plants. It should be pointed out that although there were significant correlations between the strontium-90 and minor element concentrations in the plant tissue, the entry of strontium-90 from soil to the plant appeared to be controlled by the total concentration of Ca in the soil. Thus, variations in the concentration of minor elements in the soil media is not suspected to influence the uptake of strontium-90 by plants.

TABLE 2

*Major and minor element contents of various parts of vegetable crops**

Plant material	K mg/g	P mg/g	Mn ppm	Fe ppm	B ppm	Cu ppm	Zn ppm	Al ppm	Mo ppm	Co ppm	Na ppm	SiO_2 mg/g
Beet, leaves	36.0	10.5	370	60	65	8	70	56	1.5	0.3	615	2.0
Beet, petiols	27.0	4.6	135	14	29	5	38	15	0.8	0.2	600	2.0
Beet, root	8.5	3.8	110	255	17	43	51	250	0.5	0.4	540	2.0
Cauliflower, leaves	21.5	3.9	60	52	27	5	15	62	0.3	0.6	580	2.0
Cauliflower, stems	22.0	3.5	24	26	18	4	17	21	0.2	0.3	560	2.0
Cauliflower, head	32.0	4.4	17	20	17	1	17	4	0.1	0.4	600	2.0
Celery, leaves	13.5	3.4	145	60	39	5	35	70	0.7	0.5	630	2.0
Celery, stems	16.5	3.6	64	15	43	1	14	31	0.2	0.2	590	2.0
Cucumber, leaves	21.5	8.2	85	75	62	11	49	82	1.1	0.6	325	23.0
Cucumber, stems	29.5	8.4	62	19	28	6	23	32	2.0	0.4	580	2.0
Cucumber, flower	37.5	6.5	56	115	44	18	56	60	1.1	0.4	420	19.5
Cucumber, fruit	31.5	6.0	13	19	19	2	21	4	0.1	0.3	410	2.0
Eggplant,** leaves	14.0	4.8	150	100	63	14	40	215	1.5	1.3	350	2.0
Eggplant, stems	7.8	1.8	56	13	22	5	44	15	0.2	0.3	270	2.0
Eggplant, flower	21.0	4.3	100	37	51	27	31	37	0.6	0.3	410	6.0
Hot pepper, leaves	35.0	3.1	135	60	70	9	58	110	1.0	0.8	330	2.0
Hot pepper, stems	11.5	1.1	39	14	13	14	19	16	0.3	0.4	490	2.0
Hot pepper, fruit	31.0	3.3	16	39	12	5	16	3	0.1	0.1	210	2.0
Radish, tops	47.0	4.9	71	135	56	10	40	150	1.1	0.5	640	2.0
Radish, root	52.0	5.0	32	105	27	8	32	180	0.2	0.2	645	2.0
Snapbean, leaves	19.5	5.4	120	80	40	7	28	140	1.3	1.1	9	24.5
Snapbean, stems	14.0	3.3	29	21	15	11	45	27	0.6	0.7	20	2.0
Snapbean, fruit	29.0	5.0	40	35	28	25	28	8	0.2	0.3	9	9.5
Sweep pepper, leaves	40.0	4.5	170	76	82	12	62	100	1.3	0.6	190	2.0
Sweep pepper, stems	16.5	2.8	52	23	16	8	21	19	0.6	0.2	410	2.0
Sweet pepper, fruit	25.0	3.8	20	29	13	10	14	4	0.1	0.2	50	2.0
Tomato, leaves	15.0	8.5	230	145	82	7	32	175	1.6	1.1	560	2.0
Tomato, stems	11.5	5.4	105	19	22	3	50	20	0.6	0.2	590	2.0
Tomato, fruit	23.0	3.5	11	26	12	15	20	38	0.1	0.2	410	2.0

*Values are average of three replications.

**Eggplant failed to produce fruit.

In all cases, the magnitudes of strontium-90 concentrations (mμc/g dry matter) in the aerial parts of the plants were, in descending order, leaves, stems, and fruit. However, when the strontium-90 contents for various plant parts were calculated per unit weight of Ca in the plant tissue, the Sr^{90}/g Ca ratio in stems was markedly higher than in leaves or fruit. Among the vegetable crops, highest accumulation of strontium-90 was found in cucumber plant while the least accumulation occurred in beet. The strontium-90 content of leaves from various crops ranged from 128 (mμc/g dry matter) for cucumber to 49.3 (mμc/g dry matter) for beet. These differences were associated with the Ca absorption of plants. For example, the Ca content of the cucumber leaves (30 mg/g dry tissue) was 2.3 times higher than the Ca content of beet leaves (13.0 mg/g dry tissue). However, when the strontium-90 contents were calculated as Sr^{90}/g Ca ratios, the differences between species were partially eliminated.

Considering the cation exchange capacity (CEC) of roots, Mouat (1960) working with pasture plants, observed a linear correlation between the CEC of various plant species and the uptake of strontium-90. However, in this investigation, when the CEC (mEq/100 g oven-dry weight) of different vegetable roots (which has been reported by Drake and Campbell, 1956) were compared with the strontium-90 contents of the aerial parts of plants, no linear relationships between the CEC and strontium-90 accumulation was observed.

The extent to which the edible parts of vegetable crops vary in their concentration of strontium-90 was considered. It was interesting to note that radish root accumulated considerably more strontium-90 than any other crop used in this investigation. However, it was suspected that such a high activity was not entirely due to the absorption by the radish root system, but perhaps was partially due to the surface adsorption of strontium-90 from soil media which was not completely removed from the root surface at the time of harvest. Since it is generally accepted that the strontium-90 retention by man is governed by the total amount of Ca associated with it in the diet, it is more meaningful to report the strontium-90 content of edible parts of plants in terms of Sr^{90}/g Ca ratios rather than Sr^{90}/g of dry tissue. The order of strontium-90 concentration (Sr^{90}/g Ca) in the edible portions of the plants was Radish (root) > Snapbean (fruit) > Cucumber (fruit) > Hot pepper (fruit) > Celery (stem) > Beet (root) > Celery (leaf) > Sweet pepper (fruit) > Cauliflower (fruit) > Tomato (fruit).

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LITERATURE CITED

Comar, C. L. and **J. C. Thompson, Jr.** 1963. Behavior of fallout radio-contaminants in the food chain, P. 9–23 *In* F. Haghiri and R. R. Johnson (Ed.), Proceedings of the North Central Experiment Stations Workshop on Radionuclides in Foods and Agricultural Products. Special Report Series No. 1, Ohio Agricultural Experiment Station, Wooster, Ohio.

Drake, M. and **J. D. Campbell.** 1956. Cation exchange capacity of roots as related to plant nutrition. Proc. Am. Soc. Horticult. Sci. 67: 563–569.

Duckworth, R. B. and **J. Hawthorn.** 1960. Uptake and distribution of strontium in vegetables and cereals. J. Sci. Food Agric. 11: 218–225.

Evans, E. J. and **A. J. Dekker.** 1962. Comparative Sr^{90} content of agricultural crops grown in a contaminated soil. Canadian J. Plant Sci. 42: 252–258.

Fuller, W. H. and **W. J. Flocker.** 1955. The uptake of radio-strontium by certain type crops from calcareous soils. Arizona Agric. Expt. Sta. Tech. Bull. 130.

Haghiri, F. and **J. D. Sayre.** 1961. Strontium-90 uptake by plants as influenced by soil types and liming. Soil Sci. Soc. Am. Proc. 25: 120–123.

Jones, J. B., Jr. and **F. Haghiri.** 1962. Reducing the uptake of Sr^{90} by plants on contaminated Ohio soils. Ohio J. Sci. 62: 97–100.

Menzel, R. G. and **W. R. Heald.** 1959. Sr and Ca contents of crops plants in relation to exchangeable Sr and Ca of the soil. Soil Sci. Soc. Am. Proc. 23: 110–112.

Mouat, M. C. H. 1960. Interspecific differences in strontium uptake by pasture plants as a function of root cation-exchange capacity. Nature 188: 513–514.

Neel, J. W., J. H. Olafson, A. J. Steen, B. E. Gillooly, H. Nishita, and **K. H. Larson.** Soil-plant interrelationships with respect to the uptake of fission products. I. The uptake of Sr^{90}, Cs^{137}, Ru^{106}, Ce^{144}, and Y^{91}. U. S. Atom. Energy Comm. UCLA-247.

Nishita, H., E. M. Romney, and **K. H. Larson.** 1961. Uptake of radioactive fission products by crop plants. J. Agric. Food. Chem. 9: 101–106.

Romney, E. M., J. H. Neel, H. Nishita, J. H. Olafson, and **K. H. Larson.** 1957. Plant uptake of Sr^{90}, Y^{91}, Cs^{137}, and Ce^{144} from soils. Soil Sci. 83: 369–376.

Vose, P. B. and **H. V. Koontz.** 1960. The uptake of strontium and calcium from soils by grasses and legumes and the possible significance in relation to Sr^{90} fallout. Hilgardia 29: 575–585.