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SOME ENVIRONMENTAL FACTORS INFLUENCING RADIOSTRONTIUM UPTAKE BY PLANTS *

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INTRODUCTION

Radiostrontium is foremost among the by-products of nuclear fission presently considered to be hazardous to man because it may be transmitted readily through the food chains leading to man [2 5 8 16]. The main source of radiostrontium contamination of the natural environment has been from the fallout debris of nuclear detonations. It is probable that radiostrontium may continue to be dispersed into the natural environment from other sources upon future utilization of nuclear energy. The continued production of radiostrontium has motivated studies of various factors that may inhibit the transfer of strontium through the soil-to-plant phase of the food chain leading to man. Data reported in this paper show some plant species effects and the influence of short-term variations in root temperature, light intensity and photoperiod on Sr^{90} uptake by crop plants.

MATERIALS AND METHODS

Several different species of crop plants were grown on flats containing 0 kg of Vina loam to which Sr^{90} in secular equilibrium with Y^{90} had been pplied at an activity level of 4,120 dis./sec g dry soil. White Rose potato as grown on 20 kg of Sassafras sandy loam, Hanford sandy loam, and orrento loam treated with Sr^{90} at an activity level of 128 dis./sec/g dry

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soil. Detailed properties of these soils and the methods of applying Sr^{90} to them have been reported [13]. Crop age and some identifying soil properties are shown in Table 1 and 2.

Bean and barley plants were grown on nutrient solution under light intensity of 1,000 foot-candles supplied for 16 hours of every 24-hour cycle from fluorescent tubes supplemented by Mazda lamps. Root temperature was maintained at 27° ± 1°C by placing culture jars in controlled water baths. The temperature of air filtered through activated-carbon filters varied from 27° to 30°C. Fifty barley plants and 2 bean plants per culture were grown on 3 liters of balanced nutrient solution (Ca, K and Mg = 8.33 me/l) until the environmental variables were introduced. The solutions were renewed every 6 days and continuously aerated. The environmental variables were introduced when the bean plants were 24 days old and the barley plants were 18 days old. Five replicates of each treatment were maintained. After a 24-hour stabilization period to enable the plants to adjust to the environmental changes, Sr^{90} was applied to the nutrient solution at an activity level of 5 μc Sr^{90} per liter; stable strontium was applied at the level of 1.0 me Sr per liter.

The plants were harvested after a 24-hour period for Sr^{90} absorption. This short exposure period was used to reduce the influence of altered growth rates caused by the environmental changes. One-half gram samples of dry plant tissue were radioassayed for Sr^{90} in equilibrium with Y^{90} using an end-window GM detector (1.9 mgm/cm^2). Appropriate counting corrections were applied.

RESULTS

Effect of plant species

Table 1 shows the Sr^{90} content of several different plant species grown on Vina loam. Millet obtained from two to three times more Sr^{90} than was taken up from the soil by barley, oats or wheat. For each of the grain crops, the concentration of Sr^{90} in the grain was only about one-fifth of the Sr^{90} content in the forage. The highest concentration of Sr^{90} was found in leaves of young turnip plants and swiss chard. The relative decreasing order of Sr^{90} uptake per unit dry weight of mature plant tops was turnip = millet > swiss chard > ladino clover > broccoli > soybeans > barley > oats > wheat > spinach. In a previous study with other crop plants, Romney *et al.* [13] found that the relative decreasing order of Sr^{90} uptake was radish > bean > carrot > lettuce > barley.

Very low levels of Sr^{90} were found in White Rose potato tubers in comparison to high levels found in the plant tops (Table 2). Soil

TABLE 1

Sr^{90} uptake from Vina loam * by different plant species

Plant species	Crop age, days	Sr^{90} content, dis./sec g
Cereals		
Millet, young forage	74	3,756.0
Millet, milk-stage grain	74	554.2
Millet, mature forage	95	6,659.4
Millet, dough-stage grain	95	996.7
Oats, young forage	41	1,784.4
Oats, mature leaves	182	2,142.7
Oats, ripe grain	182	1,004.4
Barley, young forage	41	2,501.0
Barley, mature forage	150	2,269.6
Barley, ripe grain	150	667.3
Wheat, young forage	41	2,082.7
Wheat, mature forage	81	1,829.7
Wheat, dough-stage grain	81	534.0
Vegetables		
Spinach	48	1,560.3
Swiss chard	72	6,109.4
Turnip, young plant	52	9,152.9
Turnip, greens	70	9,892.2
Turnip, immature root	70	4,392.9
Turnip, mature leaves	92	6,581.1
Turnip, mature root	92	3,843.0
Broccoli, edible stage	120	3,129.3
Broccoli, mature tops	145	2,485.6
Legumes		
Ladino clover, 1st harvest	108	4,872.3
Ladino clover, 2nd harvest	140	4,523.2
Soy bean, forage	62	2,685.5

* Sr^{90} activity level of 4,120 dis./sec g soil; soil pH 6.5; cation exchange capacity 14.25 me/100 g; exchangeable strontium 0.047 me/100 g; exchangeable calcium 8.20 me/100 g.

type influenced Sr^{90} uptake by potato. As was previously observed for other crop plants [13], the Sr^{90} uptake was highest from the acidic Sassafras soil which was low in calcium supply and the uptake was lowest from the Sorrento soil high in calcium supply. The inhibiting influence of calcium on strontium is attributable to

TABLE 2

Sr^{90} uptake from Sassafras, Hanford, and Sorrento soils * by potato		
Soil properties	Plant part	Sr^{90} content † dis./sec/g
Sassafras – pH 4.6		
(Cation exchange capacity 6.03 me/100 g,	Tops	5,612
exchangeable strontium 0.002 me/100 g,	Tuber skin	40
exchangeable calcium 0.40 me/100 g)	Peeled tuber	95
Hanford – pH 6.6		
(Cation exchange capacity 8.22 me/100 g,	Tops	3,136
exchangeable strontium 0.032 me/100 g,	Tuber skin	19
exchangeable calcium 4.50 me/100 g)	Peeled tuber	72
Sorrento – pH 8.0		
(Cation exchange capacity 15.10 me/100 g,	Tops	1,520
exchangeable strontium 0.070 me/100 g,	Tuber skin	14
exchangeable calcium 12.44 me/100 g)	Peeled tuber	35

* Sr^{90}-activity level of 128 dis./sec/g soil.
† Mean of 3 replicates grown 112 days.

the complementary ion relationships between these two elements [1 5 10 14]. In alkaline-calcareous soils, there is also the inhibiting influence of alkaline reaction and high bicarbonate concentration on the availability of soluble strontium.

Effect of root temperature

Barley and bean plants were grown on nutrient solutions at root temperature treatments of 27°, 17°, and 7°C. Lowering the root

TABLE 3

Effect of root temperature on 24-hour absorption of Sr^{90} by barley and beans grown on nutrient solution		
Root temperature	Sr^{90} content of dry tops (dis./sec/g)	
	Barley	Bean
27°C	563	1,140
17°C	611	1,268
7°C	189	588
L.S.D. (5%)	47.3	179.2
L.S.D. (1%)	69.3	304.3
Q10 values		
(17–27°C)	—	—
(7–17°C)	3.2	2.2

temperature from 27° to 17°C caused a significant increase ($P = 0.05$) in Sr^{90} uptake by barley. At the 7°C root temperature treatment, Sr^{90} uptake was very significantly decreased ($P = 0.01$) in barley and bean plants (Table 3). The Q10 values greater than 2.0 for plants grown at 17°C and 7°C would indicate that strontium uptake is chemically controlled rather than the result of physical phenomena; Q10 values for reactions depending only upon physical phenomena usually vary from 1.0 to 1.5.

From data presented by Hylmo [7] on calcium uptake by peas during a 24-hour absorption period, a Q10 value of 2.0 was calculated for root temperature changes from 10° to 20°C. Hoagland and Broyer [6] obtained Q10 values of nearly three for potassium uptake at root temperature change between 0.5°C and 20°C.

Effect of light intensity and photoperiod

The uptake of Sr^{90} by barley and beans from nutrient solution was significantly reduced ($P = 0.01$) when the light intensity was decreased from 1,000 to 450 foot-candles by shading the plants with sheets of cheesecloth (Table 4). The effects on Sr^{90} uptake of

TABLE 4

Effect of light intensity on 24-hour absorption of Sr^{90} by barley and beans grown on nutrient solution at 27°C

Light intensity (foot-candles)	Sr^{90} content of dry tops (dis. sec g)	
	Barley	Bean
1,000	453	1,162
450	47	167
L.S.D. (5%)	52	113
L.S.D. (1%)	117	173

varying the amount of light and darkness to which barley and bean plants were exposed during a 24-hour period are shown in Table 5. In this experiment Sr^{90} was added to the nutrient solution at the same time the photoperiod treatment was introduced. The uptake of Sr^{90} was significantly reduced at light-exposure periods of less than 12-hours duration. One-third to one-half of the total amount of Sr^{90} obtained during the 24-hour absorption period was taken up independent of exposure to light.

The influence of light on strontium uptake is probably an indirect

effect of the rise in temperature concomitant with light absorption and from photochemical reactions. A rise in temperature has been shown to cause increased transpiration rates and generally results

TABLE 5

Effect of photoperiod on 24-hour absorption of Sr^{90} by barley and beans grown on nutrient solution at 27°C

Hours of light exposure		Sr^{90} content of dry tops (dis. sec/g)	
Light	Dark	Barley	Beans
24	0	539	1,279
16	8	518	987
12	12	409	1,007
8	16	256	546
0	24	273	421
L.S.D. (5%)		105	340
L.S.D. (1%)		140	464

in increased mineral uptake. Photochemical processes are known to enhance plant uptake of inorganic salts probably by light-modified changes in permeability, viscosity, and protoplasmic streaming [3 4 17 18].

DISCUSSION

The relative degree of hazard that might arise from radiostrontium depends upon the extent to which it is transmitted through the food chains leading to man. In this respect the soil-to-plant phase of the food chain will play an important role in the event that crop-producing soils become contaminated with soluble forms of radiostrontium. Any practical means of reducing the transfer of radiostrontium from soils to plants must be considered. It has been shown that liming of soils of low calcium status will significantly reduce crop uptake of radiostrontium and that plant uptake of radiostrontium is inversely correlated with the levels of available calcium in soils [1 5 10 14]. The addition of high levels of organic matter also will inhibit radiostrontium uptake by crop plants from contaminated soils [11]. The inherent capacity of different plant species to take up more or less strontium from soils also must be considered because the difference in the amount of radiostrontium taken up by two different crop plants from the same soil may be greater than the effects produced by any practical treatment

man could apply. Certain plants or parts of plants which concentrate high levels of radiostrontium could be eliminated from the human diet, should the need arise. Fortunately, the potato tuber and the fruits and grains of most food crop plants appear to concentrate relatively low levels of radiostrontium in comparison to the foliage. Meat-supplying animals that may have to eat the plant foliage would, in turn, dilute the amount of Sr^{90} transferred to man by way of meat products.

Although it is not practical to alter soil temperature, light intensity or photoperiod over any given large agricultural area, the inhibiting effects of these environmental factors on radiostrontium uptake probably are manifest in climatic regions which experience reduced light intensity, shorter day length and cooler soil temperature.

SUMMARY

The amounts of Sr^{90} taken up from Vina soil varied among several different crop plants by a factor as high as 10 on the basis of dry weight. The relative decreasing order of Sr^{90} uptake by mature plant tops was turnip = millet > Swiss chard > Ladino clover > broccoli > soybeans > barley > oats > wheat > spinach. For each of the cereal crops, the concentration of Sr^{90} in the grain was only about one-fifth of the Sr^{90} in the forage. The tubers of White Rose potato grown on Sassafras, Hanford and Sorrento soils contained only about one-fiftieth of the Sr^{90} concentrated in the tops. The Sr^{90} uptake by potato was inversely correlated with the level of plant-available calcium in Sassafras, Hanford and Sorrento soils.

Lowering of root temperature from 17° to 7°C significantly reduced Sr^{90} uptake by barley and beans during a 24-hour absorption period. Q10 values indicated that strontium uptake was chemically controlled rather than the result of physical phenomena.

A decrease in light intensity from 1,000 to 450 foot-candle significantly reduced Sr^{90} uptake by barley and beans. The uptake of Sr^{90} also was reduced as the light exposure period was decreased. One-third to one-half of the total amount of Sr^{90} obtained during a 24-hour absorption period was taken up independent of exposure to light.

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