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Comparative Availability of Cesium and Strontium for Plant Absorption From Amended Rupert Surface Soil and Associated Subsoil: Influence of Growth Conditions

D. A. Cataldo

March 1979

Prepared for the
U.S. Department of Energy

Pacific Northwest Laboratory
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COMPARATIVE AVAILABILITY OF CESIUM AND STRONTIUM FOR PLANT ABSORPTION FROM AMENDED RUPERT SURFACE SOIL AND ASSOCIATED SUBSOIL: INFLUENCE OF GROWTH CONDITIONS

D. A. Cataldo

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Pacific Northwest Laboratory
Richland, Washington 99352

EXECUTIVE SUMMARY

Studies were undertaken to determine the plant availability of ^{134}Cs and ^{85}Sr amended to Rupert surface soil and an associated subsoil. Concentration ratios for cheatgrass (Bromus tectorum) and tumbleweed (Salsola kali) grown on ^{134}Cs amended Rupert soil were 0.15 and 0.28, respectively; values for amended subsoils were 0.074 and 0.13, respectively. Rupert surface soil and subsoil amended with ^{85}Sr gave concentration ratios of 15 and 7, respectively, for both tumbleweed and cheatgrass. While pot size (1 vs 4 kg) had a marked effect on concentration ratios, values for greenhouse and growth chamber grown plants were generally similar. Aging of both Rupert surface soil and subsoils for 1 to 30 days prior to planting had a pronounced effect on the availability of ^{134}Cs for uptake by plants, but no effect on ^{85}Sr uptake.

ACKNOWLEDGMENT

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INTRODUCTION

Much of the available literature on the uptake of cesium (Cs) and strontium (Sr) by plants deals with soil types not directly applicable to arid soils characteristic of the Hanford area. Routson (1975), using a Burbank sand, showed Cs and Sr uptake by tumbleweed to be independent of radionuclide concentration over several orders of magnitude. Reported concentration ratios (CR) for mature plants were 0.053 and 19 for Cs and Sr, respectively. These CR values are in general agreement with those using agricultural soils (Menzel, 1965; Price, 1971), although the apparent differences in CR values between Cs and Sr may be reflected in the lesser degree of Sr sorption in these calcareous low-exchange soils with differing properties (Routson, 1973). Analysis of the plant availability of Cs and Sr using five Hanford soils (Burbank, Rupert, Warden, Ritzville and Lickskillet) showed CR values to range from 0.0078 to 0.066 and 3.5 to 16 for ^{134}Cs and ^{85}Sr, respectively (Cataldo et al., 1978). Correlations of various soil parameters with uptake of Cs and Sr by cheatgrass and tumbleweed suggested that plant availability was related to cation exchange capacity (CEC) and other soil parameters affecting cation exchange capacity.

While soil parameters have a pronounced influence on the availability of radionuclides, plants have the metabolic capability to selectively absorb individual elements at differing rates. This is readily seen with plant species indigenous to the Hanford Reservation such as cheatgrass and tumbleweed. Examples of the latter include Cs and Sr (Cataldo et al., 1978), while the uptake of Tc and I appear to be relatively comparable for both species (Routson and Cataldo, 1977; Cataldo, 1978) when grown on surface soils. A further plant aspect which receives little attention when comparing the relative plant availability of radionuclides is the tissue dilution aspects inherent in the use of concentration ratios. This effect was described for Cs and Sr with respect to plant age and plant maturity (Routson and Cataldo, 1978), and Tc and I for soils not conducive to plant growth (Cataldo, 1978). However, in the present study plants were grown for only 60 days (flowering stage for tumbleweed), therefore, changes in CR values seen at full plant maturity (approximately 90 days growth) will not be observed.

The present study was undertaken to evaluate the comparative availability of Cs and Sr amended to Rupert surface soils and associated subsoils. In addition, an attempt is made to assess the effect of growth conditions such as controlled versus uncontrolled environments, pot size, and soil aging on adsorption of Cs and Sr by cheatgrass and tumbleweed.

MATERIALS AND METHODS

Plant Cultures. The plants employed in this study were cheatgrass (*Bromus tectorum*) and tumbleweed (*Salsola kali*). These annuals are introduced species that are well adapted to an arid climate and readily invade disturbed areas on the Hanford Reservation. Plants were germinated and grown in either 1 kg of soil packed into quart cartons (8.5 x 18 cm) lined with plastic or 4 kg of soil packed into capped PVC pipe (10 x 32 cm). Soils included Rupert surface soil, an adjacent subsoil, and subsoils leached with 10-column volumes of Columbia river water. Four replicates of each treatment and controls were prepared and placed in either a growth chamber maintained for 60 days with 20C day and 12C night temperatures, 14 hr photoperiod and ambient humidity (approximately 30%), or placed in a greenhouse at ambient temperature, humidity and light, except that heat was supplied at temperatures below 5C and cooling supplied at temperatures above 36C. Seedlings were thinned to a single plant per pot, irrigated 3 times a week with distilled water to maintain soil moisture 0.3 bar, and fertilized periodically with NH_4NO_3 solution added with irrigation water (total N added was 82 μg/g soil).

Soil Preparation. Soils studied were Rupert loamy sand and an adjacent subsoil. The Rupert sand was collected from an area 200 yd west of the 218-W-3a waste burial grounds and represents the upper 10 cm of soil. The subsoil was obtained from the 218-W-3a waste burial grounds, trench 13. The sand and subsoil were quartered and sieved through a 6.35 mm screen; more than 99.9% of the Rupert sand passed the screen, greater than 47% of the subsoil was retained and consisted of gravel. The less than 6.35 mm fraction of subsoil was employed in uptake studes and termed subsoil B. The Rupert sand and the subsoil B were further sieved using 2 mm and 100 mesh sieves; particle distributions are shown in Table 1. The less than 2 mm component was employed for particle size analysis, CEC, PH, (Table 2) and the less than 100 mesh was used for mineralogy studies (Table 3).

TABLE 1. Size Distributions of Soils

Particle Size	Soil	
	Rupert	Subsoil B
(mm)	(% dry wt)	
6.35	0.1	48.1
2.0 - 6.35	1.8	13.3
0.25 - 2.0	42.2	33.8
0.25	55.9	4.8

TABLE 2. Properties of Soil Samples

Property	Soil	
	Rupert	Subsoil B
Texture Class	Loamy Sand	Loamy Sand
Sand, 50 m (%)	84.1	78.8
Silt, 2-50 m (%)	8.5	5.3
Clay, 2 m (%)	7.4	15.9
CEC (meg/100g)[a]	5.3	5.7
pH	6.8	8.5
organic carbon %	0.25	0.25

[a] <2 μm soil fraction

TABLE 3. Elemental Analysis of Hanford Area Soils

Elemental Composition	Rupert	Subsoil B
Macro-ions		
	----- % -----	
Si	28.2	28.6
Al	6.28	5.77
Fe	4.92	4.55
Mg	1.26	1.29
Ca	2.93	3.42
K	1.55	1.70
Na	1.88	1.83
Ba	0.14	0.20
Micro-ions		
	---- ppm -----	
I	0.58	6.8
Br	4.5	21
Cl	14	76
F	640	960
P	2400	3700
Mo	1.6	4.5
S/SO_4 [a]	11	110
P/PO_4 [b]	10	4

[a]Available sulfur

[b]Available phosphorus

Soil Amendment and Radioanalysis. Soils were amended with ^{85}Sr and ^{134}Cs; both were supplied with carrier as described previously (Routson, 1975). The final soil concentration of Sr and Cs was 17 ng/g dry wt soil. Specific activity of spiking solutions was 3.098 μCi ^{85}Sr/μg Sr and 3.129 μCi ^{134}Cs/μg Cs. During amendment, the Rupert surface soil and subsoil B were brought to 13%

and 8% moisture by weight,respectively. Soils were held in controlled environment chambers for 1, 10 or 30 days prior to planting and subsequent maintenance under either growth chamber or greenhouse conditions. After 60 days, plants were harvested, oven dried at 60C for 12 hr, weighed, and ^{134}Cs and ^{85}Sr content determined by gamma spectrometry. CR values were calculated from activity of ^{134}Cs or ^{85}Sr/g dry wt shoot tissue divided by activity/g dry wt soil.

RESULTS

Influence of Culture Conditions on Plant Growth. Historically, studies at Hanford on the availability of radionuclides for plant absorption have employed several plants grown in quart containers containing approximately 1000 g of soil in controlled environment chambers. Under these conditions plant dry matter production is generally low (less than 1 g/ plant; Cataldo et al., 1978). In the present study, an attempt was made to determine the relationship between culture conditions, dry matter production and radionuclide absorption by plants. While this is important from the standpoint of the rate of dry matter production vs absorption rate for soils which readily support plant growth, it becomes critical in comparing soils especially those which are marginal for plant growth, such as Hanford subsoils (Cataldo, 1978).

Growth chamber experiments with tumbleweed and cheatgrass grown on Rupert surface soil and subsoil B show substantially more dry matter production with plants grown on 4 kg of soil as compared with 1 kg (Table 4). While it is unlikely that nutrients such as K, Mg, Ca, N (amended to these soils), and trace elements are limiting, phosphorus levels in these soils are minimal (Table 3) and may account for the observed effect. Analyses of total phosphorus in Rupert surface soil and subsoil B shows both to be approximately 700 ppm, with only 4 to 10 ppm being as available phosphorus (PO_4^{3-}). Comparison of dry matter production for plants grown on Rupert surface soil and subsoil B under greenhouse and growth chamber conditions show a substantial reduction in dry weight using subsoil B. This is especially pronounced with cheatgrass. Again this may represent a phosphorus problem, especially at the comparatively high pH of the subsoil (Table 2).

A comparison of plant growth under greenhouse and growth chamber conditions (4 kg treatment) shows cheatgrass to be unaffected by growth conditions, while tumbleweed exhibits a 60% reduction in dry matter production under greenhouse conditions (Table 4). It should be noted that growth chamber parameters (day/night temperatures) had been optimized for growth of tumbleweed, 20C/12C day/night (Routson and Cataldo, 1977); while earlier studies employed a 27C/16C day/night temperature regime. This resulted in an approximate 6-fold increase in dry matter production. In the present greenhouse study, maximum day temperatures were 30C and minimum night temperatures were 15C. While these

TABLE 4. Influence of culture conditions on dry matter production by tumbleweed and cheatgrass

Environment	Plant Species	Soil Type	Pot Size	Dry Matter Production[a]
Growth chamber[b]			(Kg)	(g)
	Tumbleweed	Rupert	1	2.753 ± 0.428
			4	9.410 ± 0.198
		Subsoil B	1	0.746 ± 0.321
			4	3.972 ± 1.321
	Cheatgrass	Rupert	1	1.368 ± 0.067
			4	3.785 ± 0.072
		Subsoil B	1	0.072 ± 0.019
			4	0.138 ± 0.027
Greenhouse[c]				
	Tumbleweed	Rupert	4	3.195 ± 1.443
		Subsoil B	4	1.970 ± 1.038
		Leached Subsoil B	4	0.176 ± 0.052
	Cheatgrass	Rupert	4	3.650 ± 0.482
		Subsoil B	4	0.2863 ± 0.0937
		Leached Subsoil B	4	0.0097 ± 0.0038

[a]mean ± SD (12 replicates)
[b]20C/12C dry/night temperatures, 14 hr photoperiod
[c]30C/15C dry/night temperatures, 14 hr photoperiod

differences in temperature regimes explain the reduced growth of tumbleweed under greenhouse conditions, it would appear that growth of cheatgrass is less temperature dependent. While the intent of this is not to define conditions for plant growth, an understanding of growth behavior will be necessary to adequately describe the following comparative absorption data for cheatgrass and tumbleweed grown on Rupert surface soil and subsoil B in controlled environment chambers and controlled greenhouse environments.

Plant Absorption Behavior of Cs and Sr Following Aging in Soils. Plant absorption parameters (CR values, total accumulation and tissue concentration) were measured for tumbleweed plants grown under growth chamber conditions (Table 5). Rupert soil and subsoil B were amended with ^{85}Sr and ^{134}Cs and

TABLE 5. Effect of soil aging on the absorption of ^{134}Cs and ^{85}Sr by tumbleweed grown under controlled conditions[a]

Soil Type	Aging Time	Concentration Ratio	Dry Weight (g)[b]	Tissue Content (nCi)	Tissue Concentration (nCi/g)
Strontium-85					
Rupert					
	1	23.7 ± 1.3	2.726	1974 ± 400	829 ± 32
	10	25.8 ± 4.2	± 0.385	2640 ± 718	903 ± 113
	30	25.6 ± 4.5		2602 ± 281	899 ± 148
Subsoil B					
	1	21.0 ± 12.0	0.7948	473 ± 111	743 ± 446
	10	29.2 ± 10.2	± 0.3574	746 ± 170	1024 ± 360
	30	30.7 ± 5.6		793 ± 26	1073 ± 153
Cesium-134					
Rupert					
	1	0.366 ± 0.087	2.616 ±	40.4 ± 15.9	17.8 ± 4.0
	10	0.484 ± 0.063	0.484	58.0 ± 4.2	23.6 ± 2.2
	30	0.556 ± 0.178		85.1 ± 20.2	27.2 ± 9.3
Subsoil B					
	1	0.326 ± 0.120	0.6618 ±	14.8 ± 2.2	15.7 ± 4.9
	10	0.164 ± 0.068	0.2906	4.94 ± 0.30	7.83 ± 2.50
	30	0.090 ± 0.002		1.59 ± 0.08	4.39 ± 0.12

[a] Plants grown in quart cartons containing 1 kg soil, maintained in controlled environment growth chambers for 60 days, mean + SD of 3 replicate samples

[b] Mean ± SD of 9 replicate samples

aged for 1, 10 and 30 days prior to planting. In the case of ^{85}Sr, aging of soils for up to 30 days has no effect on either CR value (approximately 26) or tissue concentration (approximately 900 nCi/g). However, the total nCi of ^{85}Sr accumulated is 4-fold higher for plants grown on Rupert soil; this appears to be related to total dry matter production. Similar studies with ^{134}Cs showed markedly different trends. CR values for both Rupert soil and subsoil B are similar for the 1 day aging period (CR = 0.34); however, tissue content of ^{134}Cs and dry weights vary as in the case of ^{85}Sr. An interesting aspect of the Cs data is that with Rupert soil, CR values for tumbleweed increase over the 30-day aging period for 0.366 to 0.556, while CR values for subsoil B decrease from 0.326 to 0.090. Similar trends in availability are seen in the concentration and content data. The relative behavior of Cs availability compared with ^{85}Sr, would suggest that an extended period of time is required for Cs equilibrium to occur in both Rupert soil and subsoil B.

Comparative Availability of ^{134}Cs and ^{85}Sr under Growth Chamber and Greenhouse Conditions. A comparison of ^{85}Sr uptake by tumbleweed and cheatgrass grown on Rupert soil and subsoil B showed uptake to be comparable (Table 6), with CR values of 15 and 7 for Rupert and subsoil B, respectively. Data for ^{134}Cs shows tumbleweed to be a better accumulator of Cs than cheatgrass. CR values for tumbleweed were 0.28 and 0.13 for Rupert soil and subsoil B, respectively; while values for cheatgrass were 0.15 and 0.074, respectively. Comparison of CR values for 1 kg treatments (Table 5) and 4 kg treatments (Table 6) for tumbleweed shows CR values and tissue concentration of both ^{134}Cs and ^{85}Sr to decrease with increased pot size. If this is in fact a function of plant growth rate vs ion absorption rate by the root (tissue dilution of radionuclides), then CR values in the field may be substantially lower than those reported here. This assumes that the reduced dry matter production seen in Table 4 results from a nutrient deficiency resulting from limited nutrients contained in pots, and which would be alleviated under field conditions.

Greenhouse studies were undertaken to determine whether there is any substantial difference in growth behavior and/or radionuclide uptake for plants as compared with growth chamber studies. Plant uptake data for tumbleweed and cheatgrass grown under greenhouse conditions are shown in Table 7. In these

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Greenhouse studies were undertaken to determine whether there is any substantial difference in growth behavior and/or radionuclide uptake for plants as compared with growth chamber studies. Plant uptake data for tumbleweed and cheatgrass grown under greenhouse conditions are shown in Table 7. In these studies, which were conducted between February and May of 1978, night temperatures were allowed to follow ambient with heat supplemented only when temperatures fell below 5C, day temperatures were maintained at less than 36C by use of a swamp cooler. Unfortunately, during the ^{85}Sr experiment the cooling system was not functional during a 2-wk period and day temperatures rose to 42C. While these temperature fluctuations had an adverse effect on tumbelweed growth (^{85}Sr experiment), they did not affect growth of cheatgrass. Even with the erratic day temperatures encountered in the greenhouse and subsequent effects on dry matter producion, CR values for both cheatgrass and tumbleweed grown on Rupert soil and subsoil B are similar to those obtained for the 4 kg growth chamber experiment. CR values for cheatgrass and tumbleweed grown on ^{85}Sr amended Rupert soil are approximately 7. CR values for both plant species were similar for ^{134}Cs amended Rupert soil (CR = 0.14) and subsoil B (CR = 0.70).

TABLE 6. Uptake of ^{85}Sr and ^{134}Cs by tumbleweed and cheatgrass grown on Rupert and Subsoil B under growth chamber conditions[a]

Plant Species	Soil Type	Concentration Ratio	Dry Weight (g)	Tissue Content (n Ci)	Tissue Concentration (n Ci/g)
Strontium-85					
Tumbleweed					
	Rupert	15.3 ± 1.2	9.536 ± 0.150	5072 ± 377	533 ± 42
	Subsoil B	7.17 ± 2.31	3.842 ± 1.262	885 ± 195	250 ± 83
Cheatgrass					
	Rupert	14.4 ± 0.9	3.761 ± 1.079	1861 ± 245	500 ± 28
	Subsoil B	7.13 ± 0.78	0.1219 ± 0.0211	30.0 ± 6.4	248 ± 10
Cesium-134					
Tumbleweed					
	Rupert	0.276 ± 0.029	9.245 ± 0.217	124 ± 2.0	13.4 ± 1.2
	Subsoil B	0.127 ± 0.012	4.160 ± 1.372	25.8 ± 4.4	6.20 ± 2.11
Cheatgrass					
	Rupert	0.148 ± 0.016	3.794 ± 0.087	27.4 ± 4.0	7.22 ± 0.97
	Subsoil B	0.074 ± 0.007	0.1416 ± 0.0364	0.501 ± 0.235	3.59 ± 0.21

[a] Plants grown on 4 kg soil, aged 10-days prior to planting, mean ± SD (n = 4)

TABLE 7. Uptake of ^{85}Sr and ^{134}Cs by tumbleweed and cheatgrass grown on Rupert and Subsoil B under green house conditions[a]

Plant Species	Soil Type	Concentration Ratio	Dry Weight (g)	Tissue Content (n Ci)	Tissue Concentration (n Ci/g)
Strontium-85					
Tumbleweed					
	Rupert	21.46 ± 2.27	0.9085 ± 0.4755	661 ± 255	758 ± 83
	Subsoil-B	9.57 ± 2.30	0.4283 ± 0.0722	138 ± 21	333 ± 81
	Leached Subsoil-B	19.76 ± 0.10	0.0880 ± 0.0410	60.1 ± 26.5	688 ± 18
Cheatgrass					
	Rupert	14.69 ± 2.49	3.1045 ± 0.5049	1573 ± 283	512 ± 91
	Subsoil-B	6.63 ± 0.80	0.3700 ± 0.1044	83.7 ± 16.6	230 ± 21
	Leached Subsoil-B	7.14 ± 2.31	0.0103 ± 0.0041	2.49 ± 0.28	258 ± 75
Cesium-134					
Tumbleweed	Rupert	0.134 ± 0.018	3.195 ± 1.443	20.0 ± 6.7	6.51 ± 0.79
	Subsoil-B	0.057 ± 0.015	1.970 ± 1.038	5.40 ± 3.61	2.81 ± 0.80
	Leached Subsoil-B	0.110 ± 0.013	0.1757 ± 0.0517	0.953 ± 0.338	5.37 ± 0.34
Cheatgrass					
	Rupert	0.136 ± 0.023	4.207 ± 0.148	28.1 ± 7.0	6.64 ± 1.01
	Subsoil-B	0.085 + 0.034	0.2026 ± 0.1163	0.710 ± 0.499	3.58 ± 1.23
	Leached Subsoil-B	0.393 ± 0.187	0.0088 ± 0.0022	0.175 ± 0.110	18.8 ± 7.7

[a]Aged 10 days prior to planting, 4 kg containers, mean ± SD (n = 4)

While the plant availability of both Cs and Sr is substantially less for subsoil B than Rupert, subsoils when exposed to environmental or leaching conditions may be physically and chemically altered thereby affecting plant availability of radionuclides. To evaluate this type of situation, subsoil B was leached with 10 column volumes of Columbia river water over a 3-wk period, air dried and amended with ^{134}Cs and ^{85}Sr. Plant absorption data for the leached subsoil is shown in Table 7. Under these conditions there is a pronounced reduction in dry matter production when subsoils are leached; this may result from loss of needed nutrients. With the exception of cheatgrass grown on ^{85}Sr amended leached subsoil, CR values are higher than unleached subsoil.

DISCUSSION AND CONCLUSIONS

The present study was designed to determine the influence of plant growth conditions on plant uptake of ^{134}Cs and ^{85}Sr from Rupert soil and an associated subsoil. While growth conditions (greenhouse vs controlled environment chambers, 1 kg vs 4 kg pots) had a pronounced effect on plant growth and dry matter production, only pot size had a pronounced effect on plant uptake as measured by concentration ratios. Tumbleweed grown in controlled environment chambers in 1 kg of soil exhibited CR values of 27 for ^{85}Sr amended to both Rupert soil and subsoil B (aged 10 days), while CR values for ^{134}Cs were 0.48 and 0.16 for Rupert soil and subsoil B, respectively. Use of 4 kg of soil with tumbleweed reduced CR values by approximately 50%, while increasing dry matter production from 3- to 5-fold. If in fact these CR values are related to relative growth ratio vs uptake ratio, then CR values in the field should most likely approximate the lower values reported. In general, for the 4 kg greenhouse and growth chamber studies, CR values calculated for ^{85}Sr uptake by both cheatgrass and tumbleweed in 4 kg experiments are comparable (CR = 15); CR values for ^{134}Cs although more variable between cheatgrass and tumbleweed, range from 0.28 to 0.06. It should be noted that while CR values reported for subsoil B are lower than for Rupert, under field conditions with increased nutrient availability and increased growth, CR values for subsoil may differ substantially from these studies. If the trends seen in the present growth data are correct, CR values will most likely be reduced. In future studies, an effort should be made to supplement essential nutrients such as phosphorus and thereby attempt to eliminate the growth reductions characteristic of pot experiments. The variability in plant growth seen under greenhouse conditions, especially for tumbleweed, appears to result from a response of plant metabolism to ambient temperature regimes. While this may limit the usefulness of greenhouse studies for annuals whose growth behavior are more temperature dependent (cheatgrass and tumbleweed); this will most likely not be the case with perennial species which are less temperature dependent.

An important aspect of these data is the effect of soil aging prior to planting on plant availability and uptake of Sr and Cs. While ^{85}Sr availability does not appear to be affected by aging, ^{134}Cs availability exhibited interesting trends. In the case of Rupert, ^{134}Cs availability and uptake increased by 50% over the 30 day period, while ^{134}Cs uptake decreased by 72% over the same period with subsoil B. Undoubtedly, physical and chemical differences between these two soils are influencing ^{134}Cs availability. Since equilibrium has apparently not been reached, it may be of value to investigate soil sorption behavior of ^{134}Cs (K_d values) both in time and under conditions of miminal soil moisture as opposed to 0 time batch analysis of K_d values.

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