MASTER

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TRANSFER OF ^{137}Cs FROM DETRITUS TO PRIMARY PRODUCER*

M. WITKAMP
ECOLOGICAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENN., UNITED STATES OF AMERICA

ABSTRACT

TRANSFER OF ^{137}Cs FROM DETRITUS TO PRIMARY PRODUCER. A combination of radiotracer, microcosm, and systems analysis techniques was used in evaluating recycling of minerals from detritus back to the vegetation. A greenhouse experiment with microcosms of increasing complexity showed the effects of millipedes and snails on ^{137}Cs movement from leaf litter to tree seedlings. Millipedes increased the organic matter content of the soil and the concentration and availability of ^{137}Cs . The increase in growth and mineral uptake by plants suggests that millipedes affect both nutrient and ^{137}Cs kinetics in similar ways. With snails there were smaller increases in ^{137}Cs turnover in soil and less tree growth than with millipedes. Snails also reduced plant growth by consuming part of the foliage. Gross transfer coefficients for movement of ^{137}Cs from detritus to plants were determined through analysis of ^{137}Cs turnover using a simulation model.

INTRODUCTION

Mineral input to the roots of most of the earth's terrestrial vegetation comes mainly from the detritus of this same vegetation. Sometimes

*Research sponsored by the U.S. Atomic Energy Commission under contract with the Union Carbide Corporation.

this transfer of minerals runs directly from litter to roots. In a tropical rainforest, for example, a large percentage of certain minerals of a fallen leaf may be reabsorbed by vegetation within a few days. At the other extreme, in boreal forests only after several hundred years are most of the accumulated and nutrients returned from detritus to the trees. In both tropical rainforests and boreal forests the inorganic soil complex is by-passed almost entirely.

Remineralization of nutrients in deciduous forest, grassland, and agriculture usually takes place at intermediate rates with half-times ranging from several months to several years. The mineral transfer pathway in these biotopes usually involves sorption by soil colloids before root uptake. Differences in productivity, such as between tropical and boreal forests, are influenced by rates of litter decay and subsequent mineralization of nutrient minerals. Decay rates, in turn, are influenced by the activity of detritus fauna. This paper evaluates primarily the effect of millipedes and snails on plant growth and mineral uptake, based on a limited set of data from an experiment on ^{137}Cs kinetics in terrestrial microcosms [1]. These data have been reworked and additional data are provided to further elucidate faunal effects on transfer of ^{137}Cs from detritus to primary producer. The new insight is put into context of the original experiment [1].

EXPERIMENTAL

One way to analyze the complex cycle of mineral transfer is to break it down into simple steps. Once these steps have been described and measured, they can be combined and their interactions can be analyzed. In terms of an actual experiment this means beginning with a simple system and a transfer mechanism such as leaching of minerals from sterile detritus. As a next step, microbes may be added to study their effect on the transfer. By adding other compartments, one by one, a series of systems of increasing complexity can eventually lead to a microcosm with all the major transfers found in the field.

Such a sequence of increasingly complex ecosystems was set up in a microcosm experiment in the greenhouse. The objective was to measure the effects of millipedes and snails on (1) The release of ^{137}Cs from litter and (2) The subsequent uptake of ^{137}Cs by tree seedlings. The basic system consisted of tree seedlings, detritus, and soil. Additions to this system were millipedes, snails, and millipedes plus snails. Millipedes were chosen as major representatives of strictly detritus feeders; snails fed on detritus but also on young leaves thus affecting the standing crop of the plants as well.

The systems were contained in clear plastic boxes (13 cm diameters, 13 cm high). Triplicated series of the boxes were slanted about 5° so soil leachate would drain out of a small spout in the low side of the bottom. Three small holes were drilled in the lids to allow gas exchange with the atmosphere. Each box contained about 5.3 g dry wt. of 1-month-old leaf litter of tulip poplar (*Liriodendron tulipifera* L.). The leaves had been collected one month after leaf drop from a stand which had previously been tagged with ^{137}Cs [2]. The approximate ^{137}Cs concentration was 50,000 dis/min. g. The leaves were placed on 200 g of washed Ottawa sand. Boxes, litter, and sand were sterilized with 12% ethylene oxide (16 hr, 0.5 atm, 40°C). The systems were reinoculated by spraying soil solution with an atomizer until saturated. Soil solutions had been prepared by shaking 100 g of litter and soil from a tulip poplar stand for 15 min in 1 liter of distilled water.

After inoculation each of nine boxes received ten seeds of a shrub *Amorpha fruticosa* L. (Indigo Bush). Each of three of these boxes were given 15 millipedes [*Dixidesmus erasus* (Loomis)] weighing a total of about 260 mg dry wt. Three more boxes received two snails (*Paravitrea* sp.) of about 150 mg wet weight each. The last three boxes received a combination of 15 millipedes and 2 snails.

At monthly intervals, for five months, a beaker with 3 ml 1 N KOH was exposed for 3 hr in the boxes with aeration holes temporarily sealed. The absorbed CO₂ was measured titrimetrically. Precipitation was simulated by adding tap water with an atomizer, until 10 ml of leachate had dripped through the temporarily opened spout into a counting tube. The ¹³⁷Cs contents of leaf litter, millipedes, snails, leachate, and one plant were measured separately. Snails, millipedes, and the plant were returned to the systems. Shrubs which grew too large for the boxes were harvested after four months. Ten new seeds were added to each box for replacement. The ¹³⁷Cs content and weight of the harvested shrubs were measured and they were returned to the litter.

After five months all compartments were dried, weighed, and ¹³⁷Cs contents were measured. Organic matter was separated from the sand with a vacuum line. The ¹³⁷Cs content of the remaining sand was corrected for internal absorption shielding (10%).

The quantities of ¹³⁷Cs in the various compartments were expressed as percentages of the initial ¹³⁷Cs content of the litter. Discrepancies between the sum of these percentages and 100%, after five months, were distributed over all compartments in proportion to their ¹³⁷Cs content. Final microbial accumulation of ¹³⁷Cs in litter was computed from a parallel experiment as the difference between the measured ¹³⁷Cs content in litter with microflora and the calculated ¹³⁷Cs content of sterile litter of the same weight [1].

Gross transfer of the initial ¹³⁷Cs in litter throughout the system was simulated using a TR 48 analog computer. It was assumed that pathways existed between all compartments (with the exception of leachate which acted as a sink) and that a flux along each pathway would change in time directly proportional to the ¹³⁷Cs content of the donor compartment. For details on calculations, model, and simulations see [1].

RESULTS AND DISCUSSION

Redistribution of Weight and ¹³⁷Cs. After five months of incubation there were obvious differences between microcosms with different composition. Weight loss of litter without decomposer animals was only 9.7% as compared with weight losses of 32% with millipedes, 23% with snails, and 48% with both species as decomposers (Table 1). There was corresponding differences in the sand. Without animals, only 2% of the initial leaf material was incorporated as humus in the sand. In the presence of millipedes, 12% of the initial litter or more than one-third of the litter loss was found in the mineral soil. Snails, on the other hand, were responsible for incorporation into soil of less than 5% of the initial litter or less than one-fourth of the litter loss. Combined action of both species was always less, either in terms of weight loss or in humus formation, than the summed effect of the single species. Seemingly there is an antagonistic effect on their breakdown and humus forming activities when both species operate simultaneously in a small area.

TABLE 1. Distribution of ^{137}Cs , weight and ^{137}Cs /unit of weight in microcosms with litter (L), millipedes (M), snails (S), and plants (P) after five months of incubation and leaching by simulated rain. Mean values of triplicate were expressed as dry weight except for snails and leachate which were wet weights. Initial ^{137}Cs in litter about $0.1\mu\text{C./box}$; initial litter about 5.3 g/box.

Systems Composition	Litter	Organic Soil	Inorganic Soil	Millipedes	Snails	Plants			Leachate	
						4th Month	5th Month	Total	5th Month	Total
Final distribution of ^{137}Cs (% of total ^{137}Cs in system)										
L+P	86.1	1.9	9.0	-	-	0.3	0.4	0.7	0.9	1.9
L+M+P	46.4	17.7	27.9	0.5	-	1.2	1.6	2.8	2.9	6.0
L+S+P	67.9	5.7	19.1	-	1.3	0.5	0.6	1.1	2.8	5.4
L+M+S+P	35.4	21.0	32.9	0.4	1.0	1.0	1.5	2.5	4.4	7.9
Final weight distribution (g/box)										
L+P	4.73	0.10	200.00	-	-	0.10	0.050	0.16	9.1	57.4
L+M+P	3.63	0.66	200.00	0.22	-	0.16	0.065	0.22	9.3	59.9
L+S+P	4.08	0.23	200.00	-	0.91	0.07	0.042	0.14	11.0	63.0
L+M+S+P	2.75	0.77	200.00	0.13	0.77	0.13	0.070	0.20	10.3	63.1
Final concentration of ^{137}Cs (% of total ^{137}Cs system/g)										
L+P	18.3	19.0	0.04	-	-	2.9	7.6	4.4	0.10	0.03
L+M+P	12.7	26.8	0.14	2.1	-	8.6	24.6	12.7	0.31	0.10
L+S+P	16.6	24.8	0.10	-	1.4	5.7	14.2	7.9	0.25	0.09
L+M+S+P	12.9	27.3	0.16	3.0	1.3	8.4	21.4	12.5	0.43	0.13

Consequences of differences in mechanical breakdown and incorporation of organic material in soil were clearly reflected in the final distribution of ^{137}Cs in the systems. Without animals, litter lost 15% of its initial ^{137}Cs over the five-month incubation period. In comparison to weight loss (10%), ^{137}Cs disappeared 1.5 times faster, indicating that ^{137}Cs is readily leached from decomposing litter. Under the influence of millipedes, however, more than half (54%) of the initial ^{137}Cs was lost, and leaf weight decreased by 32% giving a ratio of ^{137}Cs loss to weight loss of 1.7. Apparently millipede activity increased not only the rate of ^{137}Cs loss by removing litter material but also tended to increase leachability of ^{137}Cs in the remaining litter.

Increased mobility of ^{137}Cs as a result of millipede activity also was reflected in the percentages of ^{137}Cs draining out of the system in leachate. Millipedes increased ^{137}Cs drainage from 1.0 to 6.0% of the total ^{137}Cs in the systems. It is plausible that the threefold increase in organic matter incorporated in soil by millipede activity is the source of increased ^{137}Cs mobility in soil. The low ^{137}Cs content of the millipedes [0.5% of the total relative to that in their excrements incorporated in soil (19%)] suggests that very little ^{137}Cs was retained during passage through the gut. The fragmentation of leaf material exposes much of the leaf cell content and appears to increase ^{137}Cs mobility [3]. Leaching of ^{137}Cs from the system with millipedes as the only decomposer animals, was greater than from the system with snails only, while leaching from systems with snails plus millipedes was intermediate.

Effects of Faunal Activity on Plants. The activity of millipedes and snails in litter and sand clearly had an effect on growth and ^{137}Cs uptake by the plants. At the end of the first four months, plants grown in the presence of millipedes weighed 1.6 times more and contained four times more ^{137}Cs than plants grown without litter consumers. Apparently plants profited from increased leaching of minerals from surface litter and from the increased moisture holding and mineral absorption capacity of the sand as a result of feces incorporation. This effect of soil organic matter on soil minerals was indicated by a ninefold increase of ^{137}Cs inorganic as a result of millipede activity. The increased availability of ^{137}Cs in soil of systems with millipedes also caused a threefold increase of ^{137}Cs concentration in the plants. More rapid growth of plants in the presence of millipedes suggests that millipedes increase nutrient availability as they increased ^{137}Cs availability.

Newly planted seedlings also grew faster during the fifth month and concentrated more ^{137}Cs under the effects of millipede activity. Cesium-137 concentrations in young plants were about three times greater than those of the plants grown during the first four months presumably reflecting the continuously increasing availability of ^{137}Cs in the soil.

Snails also increased accumulation and concentration of ^{137}Cs on soil organic matter but not as much as the millipedes did. As a result of snail activity, ^{137}Cs concentrations in the plant about doubled, but the standing crop of plants was reduced because the snails ate part of the green leaves. Effects of the mixed millipede-snail population on plant growth were between those of the single populations, with a greater impact by millipedes than by snails. This difference in impact may be related to differences in excrement deposition. Snail excrements tended to stay in the litter layer and millipede feces were incorporated in soil. Therefore, nutrients in snail feces were less likely to become available to roots of the plants than those in millipede feces.

Simulation of ^{137}Cs Dynamics. Losses of ^{137}Cs from litter soil, leachate, fauna, and plants of the system with millipedes and snails for

the entire incubation period are indicated in Fig. 1. Radiocesium in soil increased exponentially. Faunal contents of ^{137}Cs showed an initial rise to 2.5% of the total ^{137}Cs content of the system and then decreased with diminishing ^{137}Cs concentration in food. The ^{137}Cs accumulation in leachate and plants increased rather linearly with time.

The combination of transfer coefficients and corresponding half times ($T_{1/2}$) that most closely matched the monthly ^{137}Cs contents of the compartments required only eleven transfer pathways (Table 2). The most rapid transfer (shortest $T_{1/2}$) is between fauna and soil with half of the ^{137}Cs in animals going to soil in 0.18 month or about 5.5 days. Millipedes removed half of the initial ^{137}Cs from the litter in about 5.2 months. Losses of ^{137}Cs caused by millipedes accounted for about one-third of the total ^{137}Cs lost from litter. There also was a rapid exchange of ^{137}Cs between litter and soil and back from soil to litter with half times of 2.7 and 3.1 months, respectively.

In the simulations, plants received their ^{137}Cs input from soil only. Losses of ^{137}Cs from plants were mainly to litter (leaching and loss of leaves) and to fauna. Snails required 17 months to eat half of the plants. Only very small amounts of ^{137}Cs were lost from plants to soil and leachate.

CONCLUSIONS

Transfer coefficients and ^{137}Cs contents for systems with litter, snails, millipedes and plants at the end of a five-month incubation period (Fig. 2) based on the original experiment [1] underline the involvement of litter fauna and microflora in the input of ^{137}Cs from litter to soil and the rapid exchange between organic (humus) and inorganic (mineral) soil. Knowledge of the mechanisms and dynamics of mineral elements between detritus and soil is important because soil appeared to be the only ^{137}Cs input to plants and, on a world-wide scale, detritus is the major supplier of mineral elements to soil. This experiment showed that activity of the biota played a significant role in the uptake of a mineral element and growth of the trees. The combined effect of the biota increased mineral turnover and decreased loss by leaching as compared with systems without biota. These biological effects are often overlooked and very little is known about their mechanisms, magnitude, and effect on plant growth. Even simple experiments such as with these microcosms can be effective in understanding mineral transfer from detritus to vegetation.

REFERENCES

- [1] WITKAMP, M., AND M. L. FRANK. "Cesium-137 kinetics in terrestrial microcosms." Proc. 2nd Natl. Symp. Radioecol. (D. J. NELSON, and F. C. EVANS, eds.). USAEC CONF. 670503 (1963) 635-643. U.S. Dept. Commerce, Springfield, Va.
- [2] AUERBACH, S. I., J. S. OLSON, AND H. D. WALLER. Landscape investigations using caesium-137. *Nature* 201 (1964) 761-764.
- [3] WITKAMP, M. Environmental effects on microbial turnover of some mineral elements. I. Abiotic Factors. *Soil Biol. Biochem.* 1 (1969) 167-176.

Fig. 1. Experimental data points and computer fitted curves for distribution of ^{137}Cs in litter, sand, fauna, sand leachate, and green plants during the first five months of incubation.

ORNL-DWG 71-10682

TABLE 2. Transfer coefficients (λ) in percentage of ^{137}Cs in donor compartment per month and corresponding half-times ($T_{1/2} = 69.3/\lambda$) in months used to generate ^{137}Cs curves of Fig. 1.

From \ To	Litter	Fauna	Plants	Soil	Leachate
λ in %/month					
Litter	----	13.2	0	26.0	0.8
Fauna	0	----	0	395.0	0
Plants	4.0	4.0	----	0.8	0.8
Soil	22.4	0	0.8	----	2.4
$T_{1/2}$ in months					
Litter	----	5.2	-	2.7	87.0
Fauna	-	----	-	0.18	-
Plants	17.3	17.3	----	86.6	86.6
Soil	3.1	-	86.6	----	28.9

Fig. 2. Compartment contents (percentage of total) and transfer coefficients (percentage of donor compartment/month) for ^{137}Cs movement from litter to drainage and green plants after five months of incubation.

FIGURE LEGENDS

- Fig. 1. Experimental data points and computer fitted curves for distribution of ^{137}Cs in litter, sand, fauna, sand leachate, and green plants during the first five months of incubation.
- Fig. 2. Compartment contents (percentage of total) and transfer coefficients (percentage of donor compartment/month) for ^{137}Cs movement from litter to drainage and green plants after five months of incubation.