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# ACCUMULATION AND MOBILITY OF CESIUM IN ROOTS OF TULIP POPLAR SEEDLINGS

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## ABSTRACT

Tulip poplar, *Liriodendron tulipifera* L., seedlings were stem-well tagged with cesium, periodically harvested, and separated into root and shoot compartments to determine seasonal cesium distributions in different root-diameter classes and to delineate element pathways to forest soils. The cesium concentration (μCi/g) in roots <0.1 cm in diameter averaged 1.5 and 3.0 times greater than in roots in the 0.5- to 0.1-cm- and 1.0- to 0.5-cm-diameter classes, respectively. Roots contained 24% of the seedling pool of cesium in 1 week and about 40% in 7 weeks after inoculation. Sixty-five percent of the seedling content was in the root system 8 months after tagging. On an annual basis, roots of the <0.5-cm-diameter classes contained an average of 36% of the seedling pool (root and shoot) and 72% of the root pool of cesium. This is important because small roots constituted a considerable portion of the annual turnover in these root systems. Soil content of cesium (3.37 μCi) at the termination of the study and analysis of treatment effects (aboveground inputs to soil allowed or not allowed) indicated that root processes contributed twice as much cesium to the soil during the study period as the combined aboveground processes contributed.

It is generally acknowledged that the inorganic elements in ecosystems are mobile and are continuously cycled within and among ecosystems. Much knowledge has been accumulated for cycling rates of materials for aboveground compartments, but belowground compartments have received little attention because of difficulties encountered in removing roots and observing root systems in situ. We must have knowledge of the behavior of isotopes in natural systems for proper nuclear waste disposal and feasible application of nuclear energy (Odum, 1959). An understanding of the cycling of various chemical elements is

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essential for efficient management of forest production (Auerbach, Olson, and Waller, 1964; Waller and Olson, 1967; Witherspoon, 1964; and Thomas, 1969).

Results from relatively recent studies (Witherspoon, 1964; Waller and Olson, 1967; Sandberg, Olson, and Clebsch, 1969) indicate that the turnover of material from tree roots may be important as compared with aboveground transfer. The objectives of this study were to interpret accumulation and to estimate the transfer of cesium from roots of seedlings (field grown in potted forest soils) to the soil in which they were grown by use of techniques not amenable to field studies. Roots were separated into diameter and condition (dead or live) classes in an effort to determine the role of each class in the accumulation of cesium and turnover to soil. Witherspoon (1964) indicated that in small white oak trees (*Quercus alba* L.) roots less than 0.5 mm in diameter contained approximately 13 times as much cesium per unit weight as roots up to 50 mm in diameter. All aboveground cesium inputs were eliminated for 50% of the seedlings so that the budgets for soils with and without aboveground inputs could be studied.

## MATERIALS AND METHODS

Three hundred field-grown potted tulip poplar (*Liriodendron tulipifera* L.) seedlings were each stem-well tagged with about 11 $\mu$Ci of $^{134}$Cs. The seedlings were approximately 2 years old at the time of potting. Nine trees were randomly selected from each of two treatments (aboveground transfers to soil were excluded or were allowed to occur normally) at 6-week intervals for 1 year. Treatment 1 (exclusion of aboveground transfers to soil) consisted in placing the plants under a greenhouse roof that allowed several meters clearance between the polyethylene sheeting and the plants. The structure was open-ended to allow air flow. In treatment 2, which allowed aboveground transfers to occur normally, fallen leaves and other litter (bud scales, etc.) were allowed to fall or were placed on the soil surface to decay normally through the study period. Plants under the canopy were artificially watered. Precipitation was monitored, and water equal to precipitation was applied to plants either on the day rainfall occurred or on the following day. Seedlings (nine from each treatment) were harvested, and root systems were divided into the following root-size (diameter) and condition classes: (1) roots over 1.0 cm, (2) roots 1.0 to 0.5 cm, (3) roots 0.5 to 0.1 cm, (4) roots <0.1 cm, and (5) dead roots. Dead roots were separated by color. Aboveground plant parts were separated into leaf and old and new stem components. New stem represented any growth accrued after seedlings broke dormancy. Soil samples were collected for cesium analysis by thoroughly mixing each pot of soil for each seedling three to four times and removing 2- to 3-g samples after each mixing. This provided a composite sample of 10 to 12 g of soil from each seedling. Soil leachate was sampled and analyzed for cesium throughout the study period. Plant materials were dried, weighed, and analyzed

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for $^{134}Cs$. Details of root removal, processing, and analyses are reported elsewhere (Cox, 1972). A cesium balance was maintained for plant and soil components.

Oven-dried plant and soil materials were counted in a gamma spectrometer system containing a well-type NaI-crystal detector. Samples were placed in 25- by 150-mm glass tubes and counted in the 0.55 to 0.84 MeV portion of the gamma spectrum where $^{134}Cs$ exhibits characteristic photopeaks. Efficiency and decay corrections were made against standards for similar plant-tissue components and soils.

## RESULTS AND DISCUSSION

### Cesium Concentrations

In comparison with other seedling parts, the $^{134}Cs$ concentration in small roots reached high levels 7 days after the seedlings were tagged. By July 15, the <0.1-cm-diameter roots contained over 2.1 μCi of radiocesium per gram (dry weight), whereas the concentration in roots in the 0.5- to 0.1-cm class was about 1.2 μCi/g (dry weight). Leaf concentration was about 1.0 μCi/g (dry weight). Average annual biomass and cesium content and concentration values for the seedling parts are given in Table 1. Concentration of cesium in the <0.1-cm root-size class was about 1.5 and 3.0 times greater than in roots in the 0.5- to 0.1-cm- and 1.0- to 0.5-cm-diameter classes, respectively. Leaves exhibited an average concentration (0.85 μCi/g) considerably lower than that in the <0.5-cm-diameter classes.

Cesium-134 concentrations at all periods were inversely related to the diameter of the roots. Seasonal concentrations varied simultaneously among all diameter classes, with the greater variation occurring in the smaller roots. Growth dilution, leaching, exudation, sloughing, translocation from soil and shoot parts, and other processes account for the seasonal changes in concentration.

### Seasonal Distribution of Cesium Pools in Plant Parts

Cesium rapidly shifted from above- to belowground plant parts (Table 2). One week after tagging (July 15) about 15% of the plant content of cesium was in leaves, and 57% remained in the old stem tissue. By August 25 (sample 2) the leaves reached their maximum content of 16% and by the October harvest decreased to 12%. This was attributed primarily to transfer back into woody components. Waller and Olson (1967) found that during October, before leaf fall, there was a remobilization of cesium in yellow poplar. In this study, each seedling transferred an estimated maximum average of approximately 0.95 μCi of $^{134}Cs$ to the soil by rainout and leaf fall after October 6. Estimates of leaf drop and foliage leaching before this date showed that these processes

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TABLE 1

RELATIVE COMPARISON OF AVERAGE ANNUAL $^{134}Cs$ CONCENTRATION, CONTENT BY PLANT PART, AND BIOMASS OF YELLOW POPLAR SEEDLINGS GROWN IN POTTED FOREST SOILS*

| Source | Biomass,† g (dry weight) | % total weight | $^{134}Cs$,† μCi/g | Content, μCi | % Cs |
|---|---|---|---|---|---|
| Shoot parts | | | | | |
| Old stem | 6.80 (0.20) | 54 | 0.50 (0.03) | 3.4 | 38 |
| New stem | 0.32 (0.03) | 3 | 0.81 (0.17) | 0.3 | 2 |
| Leaves‡ | 1.40 (0.13) | 13 | 0.85 (0.07) | 1.2 | 12 |
| Root-diameter classes, cm | | | | | |
| >1.0 | 0.45 (0.07) | 3 | 0.17 (0.03) | 0.1 | 3 |
| 1.0–0.5 | 1.58 (0.06) | 12 | 0.66 (0.03) | 1.0 | 12 |
| 0.5–0.1 | 1.14 (0.05) | 9 | 1.24 (0.06) | 1.4 | 15 |
| <0.1 | 1.13 (0.05) | 9 | 1.91 (0.09) | 2.2 | 23 |
| Dead roots | 0.15 (0.01) | 1 | 0.31 (0.03) | 0.1 | <1 |

*Percentage distributions provide a relative look at cesium in relation to biomass in plant parts.

†Values in parentheses are standard errors of the mean. N = 144.

‡Averages for the five sampling periods when leaves were present. Percent columns do not total 100% since N = 90 for leaves.

contributed about 0.10 μCi to the soil. Therefore a return of about 1.05 μCi of $^{134}Cs$ was estimated as maximum input for the leaf component. As much as 5% of the total radiocesium leached from tagged *Liriodendron* trees has been attributed to stem flow (Waller and Olson, 1967). Stem-flow contributions were judged as insignificant in this seedling study, however, because the stems exhibited very little surface area and were very smooth.

Summation of data in Table 2 shows that over 24% of the plant budget of radiocesium transferred to the root system in a period of 7 days, and the root system contained about 40% by August 25. The root portion of plant cesium exceeded 50% by October 6 and did not drop below this level throughout the rest of the study period. From late August to mid-November, the root pool of cesium increased over 20%. This fall transfer to the root pool coincided with senescence. The root pool contained over 65% of the plant pool of radiocesium

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TABLE 2

SEASONAL DISTRIBUTION OF CESIUM POOLS IN ABOVE- AND BELOWGROUND PARTS OF *LIRIODENDRON* SEEDLINGS*

| Date | Old stem | New stem | Leaves | Root classes >1.0 | 1.0–0.5 | 0.5–0.1 | <0.1 | Dead |
|---|---|---|---|---|---|---|---|---|
| July 15 | 57.1 | 2.5 | 15.2 | 0.8 | 7.5 | 8.1 | 8.2 | 0.6 |
| | (4.6) | (0.9) | (1.8) | (0.4) | (1.6) | (1.3) | (1.2) | (0.28) |
| Aug. 25 | 42.5 | 2.2 | 15.7 | 3.3 | 8.7 | 10.8 | 15.8 | 0.7 |
| | (4.0) | (0.4) | (2.7) | (1.1) | (1.5) | (1.3) | (2.1) | (0.18) |
| Oct.6 | 30.1 | 2.5 | 12.3 | 1.5 | 12.8 | 14.0 | 26.0 | .0.3 |
| | (1.6) | (1.0) | (1.4) | (0.8) | (1.2) | (1.0) | (1.4) | (0.07) |
| Nov. 17 | 36 0 | 1.2 | 0.0 | 2.1 | 13.6 | 17.0 | 28.9 | 0.2 |
| | (2.5) | (0.1) | (0.0) | (1.1) | (1.2) | (1.5) | (1.7) | (0.03) |
| Jan. 3 | 36.5 | 1.6 | 0.0 | 3.5 | 12.2 | 17.8 | 27.1 | 0.4 |
| | (2.7) | (0.2) | (0.0) | (1.2) | (0.9) | (1.4) | (2.2) | (0.07) |
| Feb. 14 | 39.5 | 1.6 | 0.0 | 2.3 | 14.5 | 16.5 | 24.7 | 0.4 |
| | (2.6) | (0.2) | (0.0) | (1.1) | (1.1) | (1.1) | (2.0) | (0.06) |
| Mar. 27 | 28.3 | 1.4 | 2.4 | 5.0 | 12.6 | 19.2 | 30.1 | 0.5 |
| | (1.9) | (0.2) | (0.5) | (1.4) | (0.7) | (1.2) | (2.1) | (0.1) |
| May 8 | 34.4 | 1.7 | 9.1 | 4.5 | 11.5 | 14.7 | 24.1 | 0.5 |
| | (2.5) | (0.2) | (0.6) | (1.2) | (1.2) | (1.1) | (2.2) | (0.08) |
| Grand mean | 37.9 | 1.8 | 6.9 | 2.9 | 11.7 | 14.8 | 23.1 | 0.4 |
| | (1.2) | (0.2) | (0.7) | (0.4) | (0.5) | (0.5) | (0.9) | (0.05) |

*Values in parentheses are standard errors of the mean. Because of rounding, percentages may not sum to 100%. N = 18.

by March 27. Content in the root system decreased about 12% and shoot content increased 12%, however, between the March and May harvest periods; this indicates a shift of cesium aboveground during leaf development. Although it is not indicated here, the soil content showed little change (1%) in this period. During this time the old-stem content increased from 28 to 33% of the total plant radiocesium, leaves gained 5%, and new stems gained the remainder. By May 1972 the old-stem, new-stem, and leaf compartments contained 38, 2, and 9% of the plant radiocesium, respectively. The remainder (about 51%) of the seedling content of cesium was in the root system.

## Root-Diameter-Class Distribution of Cesium

One week after tagging (July 15), the three smallest root-diameter classes (Table 2) contained about equal portions of radiocesium. With time, however, more of the isotope concentrated in the smallest diameter roots (<0.1 cm). After August 25 the <0.1-cm roots contained over 40% of the radiocesium in the root pool, and the 0.5- to 0.1-cm class averaged about 27% of the root pool. Therefore the <0.5-cm root-diameter classes contained over 65% of the root

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pool of cesium. This is of major importance since roots <0.5 cm in diameter constitute a considerable portion (>90%) of the annual turnover by mortality in these root systems (Cox, 1972).

Major net losses in the seedling root biomass and cesium pool due to death and decay occurred in late summer (August), winter (between November and March harvests), and spring (May). The total dead root material accounted for during these periods alone averaged about 0.76 g of dry weight or ~1.2 μCi of cesium per seedling. The average annual cesium concentration (1.6 μCi/g) of the two smallest root-size classes (0.5 to 0.1 cm and <0.1 cm) was applied to the actual dry weight of the dead root material collected during the study to estimate the cesium turnover by death and decay since all losses occurred in <0.5-cm root-diameter classes.

## Above- vs. Belowground Inputs of Cesium to Soil

Analysis of treatment effects (aboveground transfers to soil were excluded or were allowed to occur normally) substantiated the importance of root processes in transfer of mobile elements to soils. Average annual $^{134}Cs$ concentration (± standard error) for soils under canopies where aboveground inputs were allowed (treatment 2) was 3.04 ± 0.18 nCi/g; for soils whose contributions were primarily from roots (aboveground inputs excluded, treatment 1), it was 2.19 ± 0.27 nCi/g. Analysis of variance of soil cesium concentrations for the treatments indicated a difference among treatments at the 5% probability level. This indicated, as did previous budget estimates, that approximately 33% (1.1 μCi) of the soil cesium content was transferred from shoot components by way of rain leaching and leaf drop and that the remaining 67% (~2.27 μCi) was transferred to the soil by root processes. Leachate samples did not accumulate detectable amounts of cesium activity.

The $^{134}Cs$ content of the soil at the end of the study (May harvest) was 3.37 ± 0.41 μCi or over 32% of the total budget (10.58 ± 0.29 μCi) for the plant and soil components. The root system contained over 38% of the cesium at the termination of the study, leaving about 30% aboveground. Sandberg, Olson, and Clebsch (1969) estimated a 32% radiocesium loss from the root system of yellow poplar seedlings to a sand mixture in one growing season. That only 25% of this was attributed to root death was probably related to the unusually good aeration provided by the sand growth medium; the remaining 75% was attributed to exudation–leaching. The estimate in the present study (over 50%) is probably low since the removal of dead root material is considerably more difficult in soil than it was in sand, and only major losses were considered. Exchange phenomena, leaching, root exudation, and consumption by soil-dwelling herbivores contributed the remaining losses.

Several studies indicate that leaching and exudation of fine roots may account for sizeable cesium losses in *Liriodendron.* Waller and Olson (1967) regarded exudation and leaching processes as important root-transfer pathways

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in a cesium-tagged *Liriodendron* forest on the basis of concentrations of $^{137}Cs$ at various depths in the soil profile. Sandberg, Olson, and Clebsch (1969) estimated that 75% of the $^{137}Cs$ losses in roots of *Liriodendron* seedlings grown in sand were due to leaching and exudation. The sand growth medium probably permitted high estimates because of the lack of contact phenomena. In any case, we must be careful in extrapolating data from these artificial conditions (nutrient solutions, sand, etc.) to the soil (Rovira, 1971).

Results are in agreement with field and seedling studies, which noted that small roots rapidly accumulate high concentrations of inorganic elements (Witherspoon, 1964; Waller and Olson, 1967; Sandberg, Olson, and Clebsch, 1969) and that root processes must be responsible for returning as much material to soil as aboveground processes. The high content of cesium in small roots (<0.1-cm diameter) as compared with larger roots of the yellow poplar seedlings agrees with the relative differences noted in white oak roots by Witherspoon (1964). Determining the seasonal distribution of root biomass by diameter class appears to be very important in assessing the role of roots in the accumulation and transfer of cesium, and possibly analogous elements, since most annual turnover by mortality occurs in fine roots (<0.5 cm in diameter).

## ACKNOWLEDGMENTS

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