

Vertical variation in the transport and fate of radiocesium through the canopy via branchflow and stemflow

Zul Hilmi Saidin¹, Yuichi Onda¹, Hiroaki Kato¹, Momo Kurihara¹, Kazuki Nanko², and Delphis F. Levia³

¹Center for Research in Isotopes and Environmental Dynamics, University of Tsukuba, Tsukuba, Ibaraki, Japan
²Department of Disaster Prevention, Meteorology and Hydrology, Forestry and Forest Products Research Institute, Tsukuba, Ibaraki, Japan
³Departments of Geography, University of Delaware, Newark, Delaware, USA

Background of research

March 12, 2011 – radionuclides released from FDNPP → dry deposition (MEXT, 2011)
March 15 and 16, 2011 - 2 rainfall events → wet deposition most aerosols and water-soluble gases are washed out by a rainfall (Kinoshita et al., 2011)
Most of the radionuclides were deposited on March 15 in Fukushima prefecture (Kinoshita et al., 2011)

(Kinoshita et al., 2011)

Transportation and fate of radiocesium leaching via branchflow and stemflow

Dry and wet deposition FDNPP →
Evaporative loss due to canopy interception
Radiocesium washout through preferential flowpath
Foliage storage
Foliage translocation
Absorption by tree bark/tissues
Entrainment at tree bark
Leaching to stemflow
Deposited to soil
Forest Floor

Cedar Stand
Oak Stand

Adapted and summarized from IAEA-BIOMASS-1 (2002); 森林水文学編集委員会 (2007); and Kato et al., 2018

Research questions

- Does the upper canopy or the tree trunk serve as the larger source of ¹³⁷Cs leachates via stemflow and branchflow?
- Does branchflow and stemflow generation affect the ¹³⁷Cs leaching process?
- Does the spatial variability of ¹³⁷Cs deposition differ among cedar and oak stands?
- Does routing and residence time at tree stand affect the isotopic composition (evaporation loss) in branchflow and stemflow?

Methodology

Location of the study site:

Kawamata Town, Yamakiya District, Fukushima Prefecture

Location of the tree stands

Mixed broad-leaved forest site
Cedar forest site

Deposition of total radiocesium: 600k – 1000k Bq/m²
(Nuclear Regulation Authority, Japan
Retrieved on November 18, 2018 from [http://nra.go.jp/eng/](http://nra.go.jp/eng/eng/))

Position of branchflow and stemflow at cedar stands

Top of the canopy (mean is 10.6 m)

Cedar A
DBH: 60.3 cm
Basal area: 0.286 m²

Cedar B
DBH: 50.0 cm
Basal area: 0.196 m²

Cedar C
DBH: 59.8 cm
Basal area: 0.281 m²

Position of branchflow and stemflow at oak stands

Top of the canopy (mean is 14.3 m)

BL1
DBH: 85.57 cm
Basal area: 0.575 m²

BL3
DBH: 89.1 cm
Basal area: 0.624 m²

Laboratory analysis

- High-purity n-type germanium co-axial gamma-ray detector (EGC25-195-R, Canberra-Eurisys, Meriden, CT, USA), coupled with Amplifier (PSC22, Canberra-Eurisys, Meriden, CT, USA), and with multichannel analyzer (DSA1000, Canberra, France).
- Stable isotope of ¹⁸O and ²D of all samples was analyzed using a laser-based water isotope analyzer (L1102-4, Picarro, Inc., Sunnyvale, CA).
- Each water sample was measured by 8 times, and the mean of the later 5 time of the measurement was used for further analysis.

[Research question 1] ¹³⁷Cs partitioning at cedar and oak stands

Vertical variation of ¹³⁷Cs at cedar stands

Sampling on 27th December 2018

¹³⁷Cs Activity ±SD (Bq/L)
Stemflow Volume (L)

Cedar A
No water
2.53 ±0.26 Bq/L
0.03 L
3.04 ±0.25 Bq/L
0.28 L
4.09 ±0.35 Bq/L
0.1 L

Cedar B
No water
0.35 ±0.14 Bq/L
0.7 L
2.00 ±0.21 Bq/L
0.7 L
2.35 ±0.22 Bq/L
0.2 L

Cedar C
No water
0.62 ±0.17 Bq/L
0.6 L
7.23 ±0.41 Bq/L
0.23 L
3.17 ±0.20 Bq/L
0.08 L
10.00 ±0.56 Bq/L
0.05 L

YC
6.60 ±0.35 Bq/L
0.05 L
GS

¹³⁷Cs Mean SF Depth
1.87 Bq/L 2.45 L/m²
1.02 Bq/L 3.35 L/m²
2.95 Bq/L 3.35 L/m²

Funnelling Ratio
0.2
0.7
0.2
0.01

¹³⁷Cs concentration was larger from dead foliage as compared to mixed and young foliage at the branchflow.

Vertical variation of ¹³⁷Cs at Oak stands

Sampling on 27th December 2018

¹³⁷Cs Activity ±SD (Bq/L)
Stemflow Volume (L)

BL1
3.97 ±0.36 Bq/L
0.04 L
5.39 ±0.38 Bq/L
0.73 L
9.31 ±0.35 Bq/L
11 L
11.07 ±0.37 Bq/L
0.25 L

BL3
7.54 ±0.19 Bq/L
0.17 L
No water
11.28 ±0.44 Bq/L
0.05 L
16.25 ±0.39 Bq/L
0.3 L

BL4
GS
16.28 ±0.38 Bq/L
1.6 L

BL5
GS
10.00 ±0.36 Bq/L
0.6 L

¹³⁷Cs Mean SF Depth
9.09 Bq/L 6.13 L/m²
1.76 Bq/L 6.13 L/m²
16.28 Bq/L 2.78 L/m²
10.00 Bq/L 2.48 L/m²

Funnelling Ratio
1.3
0.4
0.17
0.15

Radiocesium leached more in lower stemflow of the trunk compared to upper trunk stemflow, possibly due to the increased residence time of stemflow on the lower reaches of the trunk.

[Research question 2] ¹³⁷Cs leaching via branchflow and stemflow generation

A) Branchflow at cedar stands
137Cs concentration via branchflow (Bq L⁻¹)
Branchflow volume (L)

B) Stemflow at cedar stands
137Cs concentration via stemflow (Bq L⁻¹)
Stemflow volume (L)

C) Branchflow at broadleaved stands
137Cs concentration via branchflow (Bq L⁻¹)
Branchflow volume (L)

D) Stemflow at broadleaved stands
137Cs concentration via stemflow (Bq L⁻¹)
Stemflow volume (L)

[Research question 3] Spatial variability of ¹³⁷Cs deposition

Sampling on 27th December 2018

Cedar A
Branchflow young foliage: Not detectable
Branchflow mixed foliage: No water
Branchflow dead foliage: 5% (1 branch) 0.22 Bq/m²
Stemflow upper: 64% 2.92 Bq/m²
Stemflow lower: 31% 1.43 Bq/m²
137Cs Depositional Flux per Tree: 4.6 Bq/m²

Cedar B
Branchflow young foliage: Not detectable
Branchflow mixed foliage: 6% (1 branch) 0.64 Bq/m²
Branchflow dead foliage: 11% (3 branches) 1.27 Bq/m²
Stemflow upper: 63% 7.14 Bq/m²
Stemflow lower: 21% 2.34 Bq/m²
137Cs Depositional Flux per Tree: 11.4 Bq/m²

Cedar C
Branchflow young foliage: No water
Branchflow mixed foliage: 13% (2 branches) 1.28 Bq/m²
Branchflow dead foliage: 60% (3 branches) 5.91 Bq/m²
Stemflow upper: 9% 0.90 Bq/m²
Stemflow lower: 18% 1.78 Bq/m²
137Cs Depositional Flux per Tree: 9.88 Bq/m²

YC
Stemflow lower: 100% 1.19 Bq/m²
137Cs Depositional Flux per Tree: 1.19 Bq/m²

BL1
Branchflow upper foliage: 0.15% (1 branch) 0.28 Bq/m²
Branchflow middle foliage: 4% (2 branches) 6.81 Bq/m²
Stemflow upper: 94% 178.17 Bq/m²
Stemflow lower: 3% 4.81 Bq/m²
137Cs Depositional Flux per Tree: 190 Bq/m²

BL3
Branchflow upper foliage: 19% (1 branch) 2.06 Bq/m²
Branchflow middle foliage: No water
Stemflow upper: 9% 0.94 Bq/m²
Stemflow lower: 72% 7.81 Bq/m²
137Cs Depositional Flux per Tree: 10.8 Bq/m²

BL4
Stemflow lower: 100% 45.31 Bq/m²
137Cs Depositional Flux per Tree: 45 Bq/m²

BL5
Stemflow lower: 100% 24.80 Bq/m²
137Cs Depositional Flux per Tree: 25 Bq/m²

[Research question 4] Isotopic composition via branchflow and stemflow

δ¹⁸O (‰)

Open Rainfall
Throughfall
Stemflow Upper Cedar
Stemflow Upper Oak
Stemflow Lower Cedar
Stemflow Lower Oak
Branchflow Cedar
Branchflow Oak
Linear (LMWL)
Linear (GMWL)

28th September 2018
27th December 2018
9th November 2018
2nd March 2019

Isotopic composition of branchflow was generally enriched in δ¹⁸O and δD compared to open rainfall and throughfall.

However, the differences in enrichment between branchflow and stemflow remain unclear.

Conclusions

- Focusing on the tree stand, the results of ¹³⁷Cs concentration shows that the canopy remained the major contribution of the ¹³⁷Cs leaching. Interestingly, branchflow of dead foliage showed the highest ¹³⁷Cs concentration as compared to branchflow of mixed and younger foliage due to interception during initial fallout.
- Branchflow and stemflow generation did not affect the ¹³⁷Cs leaching process. A higher range of ¹³⁷Cs leaching was detected even though a small branchflow volume was collected.
- Significant variability of ¹³⁷Cs depositional flux per tree stand was detected among the tree species and between cedar stand and oak stand, with the oak stand generally exhibiting higher a ¹³⁷Cs depositional flux than the cedar stand.
- The magnitude of isotopic variation differed between cedar and oak stands. However, more sampling work is needed especially during rainfall period at summer.

References

IAEA-BIOMASS-1, 2002. Modelling the migration and accumulation of radionuclides in forest ecosystems, *International Atomic Energy Agency*, Forest WG.
Kato, H. et al., 2018. Six-year monitoring study of radiocesium transfer in forest environments following the Fukushima nuclear power plant accident. *Journal of Environmental Radioactivity*. Available at: <https://www.sciencedirect.com/science/article/pii/S0265931X17308159> [Accessed February 20, 2019].
Kinoshita, N., Sueki, K., Sasa, K., Kitagawa, J., Ikarashi, S., Nishimura, T., Wong, Y.-S., Satou, Y., Handa, K., Takahashi, T., Sato, M., Yamagata, T., 2011. Assessment of individual radionuclide distributions from the Fukushima nuclear accident covering central-east Japan. *Proc. Natl. Acad. Sci. U.S.A.* 108, 19526-19529.
MEXT, 2011. Preparation of Distribution Map of Radiation Doses, etc. (J).
森林水文学：森林の水のゆくえを科学する、森林水文学編集委員会、森北出版株式会社第9章森林への物質の沈着と樹冠の相互作用、智和正明、より引用

Contact information

zhsaidin@gmail.com | s1730214@s.tsukuba.ac.jp

Linked in

