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Progress of the Joint Research Project on Sulfur Dynamics in Forest Ecosystems in Thailand, Malaysia and Japan

Network Center for EANET

1. Background

Atmospheric deposition of sulfur (S) compounds may gradually decrease according to the recent emission inventories in East Asia (e.g. Lu et al. 2010). However, the S deposition level is still high and cumulative load of S is quite large in the EANET region. Since S deposited on ecosystems may be retained in soil and/or cycled in the soil-plant system, manifestation of its effect may be delayed. In fact, in US and Europe, it was reported that S accumulated in the past has been leaching to streams in forest area recently (e.g. Mitchell and Likens 2011). Moreover, several rivers/lakes for monitoring on inland aquatic environment in the EANET countries showed pH-declining trend with SO_4^{2-}-increasing trend (EANET 2011). Effect of S deposition on terrestrial ecosystems is still one of the important issues to be investigated in the EANET region.

2. Project outline

Scientists from the Network Center (NC) and the EANET countries have been promoting the catchment-scale analysis in different types of forests, namely in Kajikawa site, Niigata, Japan, in Sakaerat site, Nakhon Ratchasima, Thailand and in Danum Valley site, Sabah, Malaysia, since 2002, 2005 and 2008, respectively. Taking account of the background above, the research team studied S dynamics in the forest catchments by the research grant from Asia Pacific Network on Global Change Research (APN) since 2012.

2.1. Title and duration

Project title: "Dynamics of sulphur derived from atmospheric deposition and its possible impacts on the East Asian forests (ARCP2012-18NMY-Sase; ARCP2013-CMY-Sase)"

Duration: From August 2012 to July 2015

2.2. Objectives

- To clarify sulphur dynamics (flux, retention time, speciation of accumulated sulphur compounds, etc.) in ecosystems of the East Asian forests

- To discuss combined effects of sulphur and nitrogen on acidification and eutrophication of the East Asian forests

2.3. Study sites

Study sites and the methods applied in the respective sites were shown in Table 1. Fluxes of ions including SO_4^{2-} had been studied by previous projects since 2002, 2005 and 2008 in Kajikawa, Sakaerat and Danum Valley sites, respectively. However, the surveys in these sites were mostly finished in 2010/2011. In 2012, the study sites were reactivated for the APN project and the rehabilitated forest in Bintulu was added as a new site for the APN project.

Table 1. Study sites and applied methods

Site	Kajikawa	Sakaerat	Danum Valley	Bintulu
State/Country	Niigata, Japan	Nakhon Ratchasima, Thailand	Sabah, Malaysia	Sarawak, Malaysia
Forest type	Japanese cedar	DEF	Tropical rainforest	Rehabilitated Forest
Applied methods for deposition	Bulk sampling of rainwaters from RF, TF, and SF	Bulk sampling of rainwaters from RF, TF, and SF IER sampling	IER sampling	IER sampling
Applied methods for soil solution	Water sampling using the porus cup	IER sampling	IER sampling	IER sampling
Applied methods for stream water	Water sampling	Water sampling IER sampling for S isotopic analysis	Water sampling IER sampling for S isotopic analysis	Water sampling IER sampling for S isotopic analysis
Start year	2002	2005	2008	2012

Note. DEF, dry evergreen forest;RF, rainfall outside forest canopy; TF, throughfall; SF, stemflow; IER, ion-exchange resin

Field surveys were conducted to determine the fluxes of ion constituents by rainfall outside forest canopy (RF), throughfall (TF) and stemflow (SF), and stream water (SW). In addition to water sampling, the data obtained from the ion-exchange resin (IER) sampling were also be used for this purpose. Ion concentrations in the water samples and extract samples from IER were determined using ion chromatograph. The ionic analysis was carried out in ACAP, Japan or ERTC, Thailand. In the case of Kajikawa, Sakaerat and Danum Valley sites, fluxes of ion constituents were determined by the previous projects. The existing data were utilized to summarize the fluxes in these sites.

To obtain enough amounts of the samples for S isotopic analysis, "IER sampling" was applied in Sakaerat, Danum Valley and Bintulu sites (see Table 1). The SO_4^{2-} extracted from the resin samplers or that in water samples were concentrated by evaporating water on hot plate and then precipitated as $BaSO_4$ by using $BaCl_2$. The S isotopic ratio in the powdered $BaSO_4$ is analyzed by using the Elemental analyzer (EA) - Mass Spectrometer (MS). The S isotopic analysis was carried out in ACAP, while the pre-treatment was carried out partly in UPM, too. Isotopic ratio of S compounds ($^{34}S/^{32}S$) may be changed by biological process (isotope fractionation). S isotopic ratio of rainwater and SW was measured to discriminate origin of S (atmospheric, biological or geological origin) and to discuss retention time of S in the ecosystems. S isotopic ratio is expressed as:

$$\delta^{34}S\ (‰) = \{(^{34}S/^{32}S)_{sample}/(^{34}S/^{32}S)_{CDT} - 1\} \times 1000$$

where, $(^{34}S/^{32}S)_{sample}$ and $(^{34}S/^{32}S)_{CDT}$ were isotopic ratios of sample and Canyon Diablo troilite (standard substance), respectively.

3. Major outcomes from the project

Fluxes of S and N:

Inputs of S and N by TF (+SF) under forest canopy and the outputs by SW in the study catchments were summarized in Table 2. The mean SO_4^{2-} concentrations in SW were 101, 73, 39, and 6.3 $\mu mol_c\ L^{-1}$ in Kajikawa, Bintulu, Danum Valley, and Sakaerat sites, respectively.

Table 2. Fluxes of S and N in the study catchments

Site		Kajikawa	Sakaerat	Danum Valley[*4]	Bintulu
Annual precipitation (mm)		2,281	1,488	2,700	3,500
S (kg S ha^{-1})	Input[*1]	28.5[*2]	5.76[*2]	3.6[*3]	19[*3]
	Output	21.6	0.16	6.0	NA
N (kg N ha^{-1})	Input	16.6[*2]	7.9[*3]	6.2[*3]	11.8[*3]
	Output	9.3	0.1	1.6	NA

Note. [*1] Input by TF (+SF) under forest canopy; [*2] By water sampling of TF+SF; [*3] By IER sampling of TF; [*4] After Yamashita et al. (2014).

S isotopic ratio of rainwater, soil solution and stream water:

The S isotopic ratio ($\delta^{34}S$, ‰) of RF, SS and SW was summarized in Table 3. The $\delta^{34}S$ values of

RF were quite different among the sites. Since the study sites were located in different countries, sources of atmospheric S might also be different. Even within Borneo Island, the values are slightly different between those at Danum Valley sites, Sabah and Bintulu sites, Sarawak. The $\delta^{34}S$ values of SW may be informative to discuss dynamics of S in ecosystems and its origin. In Kajikawa site, the annual weighted mean $\delta^{34}S$ value of SW was mostly similar to that of RF. As a possible source of S, atmospheric deposition can be considered. In Sakaerat, the $\delta^{34}S$ values of SW were sometimes significantly larger than those of RF. In addition to effects of atmospheric deposition, effects of biological fractionation (bacterial dissimilatory S reduction, BDSR) can be considered. On the other hand, in the $\delta^{34}S$ values of SW in Danum Valley and Bintulu were sometimes significantly smaller than those in RF. In addition to effects of atmospheric deposition, effects of geology (rock weathering) can be considered. The $\delta^{34}S$ values of SS were basically in between those of RF and SW.

Table 3. S isotopic ratios in the study catchments

Site		Kajikawa	Sakaerat	Danum Valley	Bintulu
S isotopic ratio ($\delta^{34}S$, ‰)	RF	8.83 (2.3 – 12.3)	4.1	10.1	7.9
	SS	6.7 – 10.5	2.0 – 9.3	6.5 – 9.6	4.4 – 11.7
	SW	9.28 (8.4 -10.0)	2.6 – 10.4	2.6 – 8.2	–4.1 – +14.3
Possible source of S in SW		AD (including sea salt)	BDSR AD (seasonally)	Rock weathering AD (high flow period)	Rock weathering AD (seasonally)

Note. RF, Rainfall outside forest canopy; SS, soil solution; SW, stream water; AD, atmospheric deposition; BDSR, bacterial dissimilatory S reduction

<u>Analysis of the long-term data in Kajikawa and Sakaerat sites:</u>

As shown in Table 1, the surveys in Kajikawa and Sakaerat sites started in 2002 and 2005, respectively. Relatively long-term data have been accumulated in these sites. Based on the analysis of the long-term data, sensitive responses to changes in atmospheric conditions have been found in both catchments. Trends of atmospheric deposition and SW chemistry were summarized in Table 4. Actually, S deposition has been declining in both sites. However, reactions to the changes in the deposition were completely different. Increase of alkalinity with decline of SO_4^{2-} concentration was observed in SW of Kajikawa site, while decline of pH with increase of SO_4^{2-} concentration was observed in SW of Sakaerat site. This may mean recovery from acidification and progress of acidification, respectively. In the case of Kajikawa site, although SO_4^{2-} concentration in SW is declining, NO_3^- concentration is still increasing year by year, suggesting progress of nitrogen saturation.

Table 4. Trends of atmospheric deposition and stream water chemistry

	Kajikawa	Sakaerat
Atmospheric deposition	Decline of S deposition	Decline of S deposition
Stream water	Increase of alkalinity Decline of SO_4^{2-} concentration Increase of NO_3^- concentration	Decline of pH Increase of SO_4^{2-} concentration
	Recovery from acidification? Progress of nitrogen saturation?	Progress of acidification?

Project seminars in Malaysia and Thailand:

"The APN (Project) Workshop on Sulphur Dynamics in East Asian Forests" was held in Malaysia and Thailand in 2013 and 2014, respectively, as follows:

- In Selangor, Malaysia: 24 June 2013 (with the field trip on 25 June)
- In Bangkok, Thailand: 18 December 2014 (with the field trip on 19 December)

The 40 - 45 participants from universities, institutes and governmental agencies attended the respective workshops. Progress and outcomes of the project were presented and active discussion was made. Moreover, possible future research topics were discussed in the workshops.

4. Conclusion

We studied S derived from atmospheric deposition and it dynamics in forest ecosystems, utilizing S isotopic analysis, and identified possible S sources in the ecosystems. Effects of atmospheric S deposition on SW chemistry were also identified in all the sites, although magnitude and types of the effects were different between the sites. In particular, our trials in Thailand and Malaysia are the first biogeochemical catchment studies using isotopic analysis in Southeast Asia. The project outcomes will contribute to development of biogeochemical studies in Asia. We also found that climate, geology and feature of the ecosystems should carefully be taken into consideration for evaluation of S dynamics in Northeast and Southeast Asia. Our findings will be shared with the EANET community and will contribute to evaluation of atmospheric S impacts in this region. Moreover, the data will be utilized for modeling, which may contribute to policy making in future.

The final report with some more detailed discussion is disclosed on the website of the APN in the following URL:
http://www.apn-gcr.org/resources/items/show/1757

References

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