Supplementary Material for Manuscript II

High nitrate and sulfate leaching in response to wetter winters in temperate beech forests

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Fig. A.1. Visual impression of the experimental construction (RnoS) with the rain collection roof to the left and the snow-out shelter to the right. The target tree is marked with a black dot.

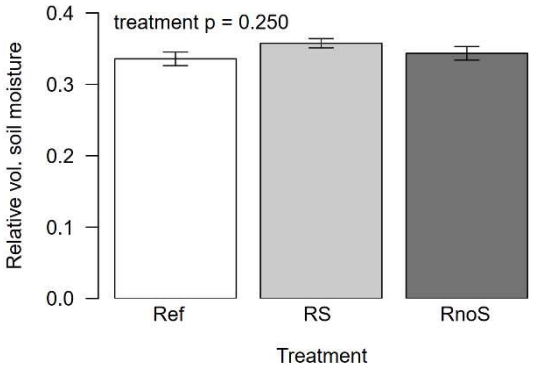

Fig. A.2. Relative volumetric soil moisture during the treatment winter 2021/22 measured in 15 min intervals in the upper 14 cm at nine forest sites between Rostock and Gdansk with the three winter treatments at each site. Bars show means and standard errors and the p-value results from the ANOVA of the linear mixed effects model.

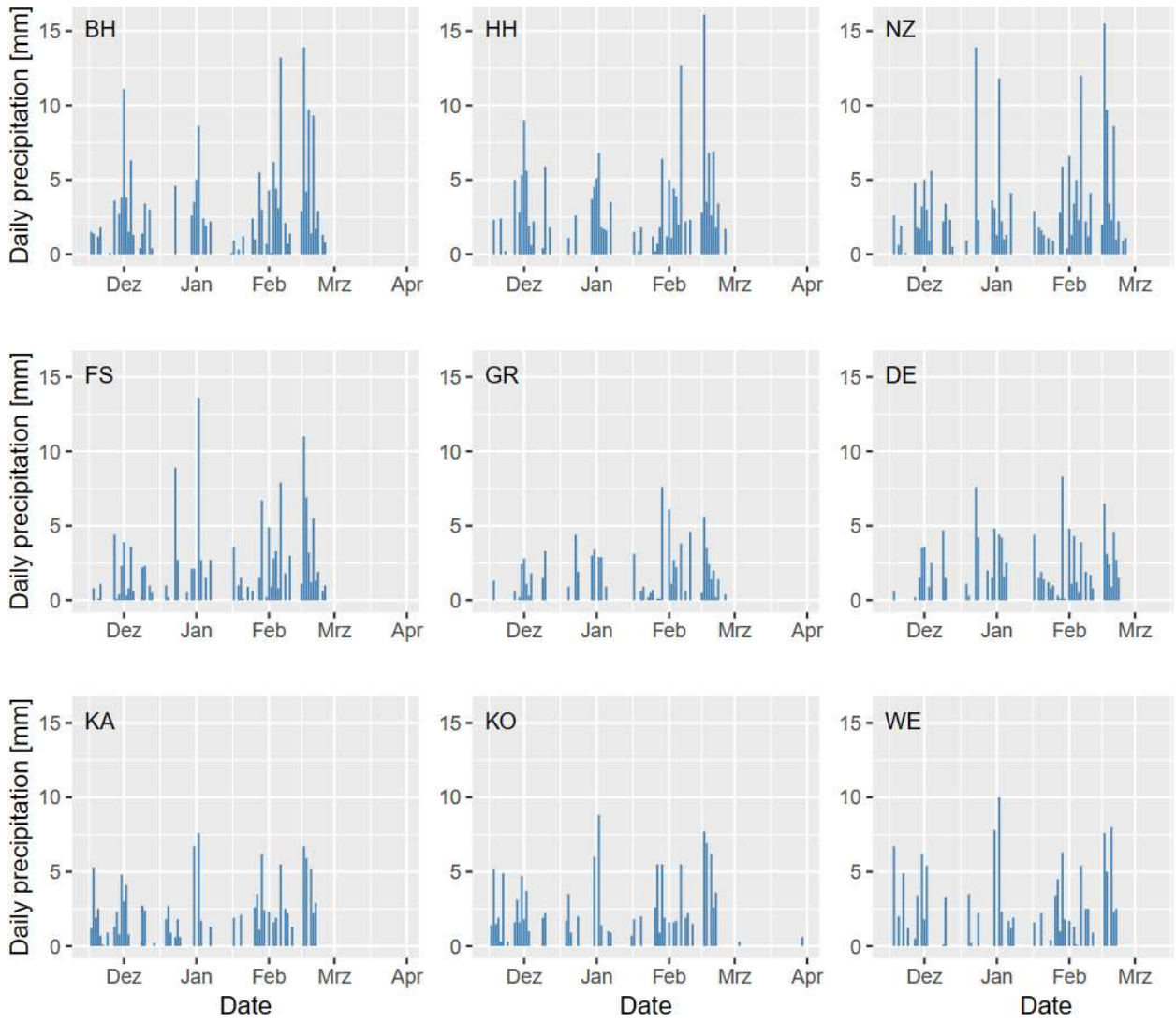

Fig. A.3. Precipitation pattern during the treatment period from mid-November 2021 to end of March 2022 at the nine study sites. Bars show absolute amounts of daily precipitation (Haylock et al., 2008).

Table A.1. List of R-packages used for statistical analyses.

Package	Reference
emmeans	Lenth, R. (2023). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.8.5. Retrieved from https://CRAN.R-project.org/package=emmeans.
lmerTest	Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(13). https://doi.org/10.18637/jss.v082.i13
minpack.lm	Elzhov, T. V., Mullen, K. M., Spiess, A., & Bolker, B. (2023). minpack.lm: R Interface to the Levenberg-Marquardt Nonlinear Least-Squares Algorithm found in MINPACK, Plus Support for Bounds. R package version 1.2-4. Retrieved from https://CRAN.R-project.org/package=minpack.lm.
multcomp	Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, *50*(3), 346–363.
sciplot	Morales, M., Team wcdbtRDC, community wgaftRl, & Murdoch. eD (2020). sciplot: Scientific graphing functions for factorial designs. R package version 1.2-0. Retrieved from https://CRAN.R-project.org/package=sciplot
tidyr	Wickham, H., Vaughan, D., & Girlich, M. (2023). tidyr: Tidy Messy Data. R package version 1.3.0. Retrieved from https://CRAN.R-project.org/package=tidyr
tidyverse	Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., . . . & Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

Table A.2. Amount of water added to the RS and RnoS plots in mm for each treatment site during the treatment winter 2021/22 (Haylock et al., 2008).

Site	Amount of added water [mm]
BH	71
HH	69
NZ	76
FS	55
GR	35
DE	46
KA	48
KO	51
WE	51

Table A.3. Nutrient availability in the topsoil and leaching (L) in 50 cm depth (both in µg/10cm² membrane surface) determined by PRS probes at the nine forest sites for three target trees per site with one winter treatment each (Reference, Rain addition with snow, Rain addition with snow exclusion). Mean and standard deviation for the entire observation period from November 2021 to July 2022 as well as F- and p-values of the mixed model ANOVA are displayed.

	Winter - Ref	**Winter - RS**	**Winter - RnoS**	**Summer - Ref**	**Summer - RS**	**Summer - RnoS**	**Treatment**		**Treatment:season**	
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**F-value**	**p-value**	**F-value**	**p-value**
NO_3-N	28.5 ± 40.3	45.7 ± 36.6	46.0 ± 30.6	26.7 ± 20.4	25.5 ± 17.5	27.1 ± 25.5	7.4	0.004 **	7.7	0.002 **
NO_3-N (L)	9.45 ± 15.1	22.9 ± 23.8	24.5 ± 17.4	6.00 ± 4.20	5.40 ± 2.84	5.45 ± 3.17	4.5	0.016 *	4.4	0.018 *
NH_4-N	12.9 ± 6.82	16.5 ± 11.1	13.9 ± 6.37	15.8 ± 10.5	15.6 ± 4.95	16.5 ± 6.07	0.5	0.604	0.1	0.867
S	42.2 ± 21.6	53.8 ± 25.1	56.4 ± 24.7	26.0 ± 9.89	27.0 ± 10.3	29.0 ± 15.3	3.3	0.044 *	1.9	0.168
S (L)	64.1 ± 51.0	104 ± 75.3	103 ± 38.4	10.7 ± 7.67	19.7 ± 20.2	10.0 ± 9.05	2.1	0.146	4.8	0.016 *
Ca	848 ± 490	790 ± 336	922 ± 512	582 ± 432	482 ± 229	686 ± 462	0.8	0.454	0.5	0.598
K	351 ± 148	316 ± 175	398 ± 210	482 ± 200	480 ± 204	474 ± 217	1.2	0.318	0.5	0.620
P	6.48 ± 5.65	6.66 ± 8.99	6.81 ± 8.86	9.77 ± 4.67	11.5 ± 7.48	11.3 ± 9.47	0.1	0.906	0.4	0.690
P (L)	1.04 ± 1.02	2.08 ± 2.09	0.84 ± 0.72	0.66 ± 0.68	1.59 ± 2.88	0.60 ± 0.61	1.2	0.317	0.2	0.835
B	0.56 ± 0.35	0.20 ± 0.20	0.48 ± 0.44	0.47 ± 0.29	0.38 ± 0.27	0.45 ± 0.17	3.9	0.039 *	1.4	0.270
B (L)	0.07 ± 0.08	0.19 ± 0.24	0.07 ± 0.11	0.13 ± 0.13	0.13 ± 0.13	0.10 ± 0.06	1.0	0.385	0.5	0.598
Fe	20.2 ± 13.7	16.8 ± 6.66	21.5 ± 11.4	10.5 ± 4.54	9.05 ± 2.71	11.2 ± 5.55	1.0	0.377	0.04	0.964
Fe (L)	8.57 ± 5.68	9.11 ± 3.28	7.98 ± 1.80	4.44 ± 1.82	5.62 ± 2.26	3.87 ± 1.15	2.1	0.153	1.3	0.289
Mn	54.6 ± 39.4	64.9 ± 31.1	69.0 ± 46.2	44.3 ± 27.2	48.1 ± 34.2	54.5 ± 37.1	1.1	0.349	0.5	0.596
Mn (L)	7.32 ± 7.68	8.22 ± 6.52	6.48 ± 4.37	2.15 ± 1.86	2.53 ± 2.10	1.79 ± 1.38	0.3	0.795	0.6	0.539
Cu	1.44 ± 0.64	1.21 ± 0.42	1.37 ± 0.46	3.15 ± 1.32	2.96 ± 1.24	3.45 ± 1.44	0.9	0.424	0.2	0.189
Cu (L)	0.65 ± 0.35	0.67 ± 0.28	0.59 ± 0.16	0.99 ± 0.51	1.08 ± 0.50	1.05 ± 0.59	0.3	0.771	0.1	0.904
Zn	6.90 ± 4.30	7.19 ± 4.77	8.96 ± 5.54	4.38 ± 1.65	5.74 ± 5.28	6.89 ± 3.60	1.6	0.224	0.1	0.900
Zn (L)	4.25 ± 3.32	3.60 ± 2.17	3.52 ± 1.39	1.70 ± 0.88	1.48 ± 0.32	1.23 ± 0.23	0.2	0.785	1.4	0.252
Pb	2.96 ± 2.61	2.35 ± 1.22	2.98 ± 1.76	1.46 ± 0.58	1.13 ± 0.46	1.56 ± 0.74	2.9	0.134	0.1	0.875
Pb (L)	0.38 ± 0.63	0.52 ± 0.50	0.44 ± 0.32	0.20 ± 0.13	0.24 ± 0.17	0.15 ± 0.05	1.0	0.398	0.9	0.416
Al	47.7 ± 21.7	52.8 ± 19.3	57.7 ± 19.1	25.7 ± 8.26	23.2 ± 6.57	28.7 ± 9.70	1.9	0.175	0.7	0.489
Al (L)	37.5 ± 21.3	40.9 ± 27.5	43.7 ± 16.4	14.5 ± 10.5	16.9 ± 13.0	12.0 ± 6.33	0.1	0.915	2.9	0.070
Cd	0.06 ± 0.07	0.04 ± 0.04	0.04 ± 0.06	0.01 ± 0.03	0.00 ± 0.00	0.01 ± 0.03	1.2	0.308	0.6	0.561
Cd (L)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	-	-	-	-

Table A.4. Deposition rates averaged for the years 1017-2021 for deciduous forests at the nine study sites in kg/ha (Norwegian Meteorological Institute, 2023). Winter data refer to the treatment period between from mid-November to end of March. Total N is the sum of NO_3-N and NH_4-N deposition.

Site	**NO_3-N**	**NO_3-N winter**	**NH_4-N**	**NH_4-N winter**	**total N**	**total N winter**	**oxS**	**oxS winter**
BH	6.61	1.87	10.63	2.84	16.45	4.66	1.65	0.59
HH	5.84	1.76	8.90	2.35	14.05	4.07	1.59	0.58
NZ	5.56	1.75	6.81	1.70	11.60	3.40	1.88	0.73
FS	5.36	1.77	6.46	1.58	11.09	3.31	2.13	0.81
GR	6.13	1.92	8.50	1.,99	13.87	3.87	3.03	1.13
DE	5.72	1.93	7.12	1.88	12.04	3.76	2.71	1.14
WE	4.95	1.54	5.86	1.11	10.19	2.62	2.56	0.92
KA	4.74	1.50	7.30	1.49	11.51	2.97	3.01	1.14
KO	4.82	1.52	6.31	1.22	10.60	2.72	2.97	1.07
Mean	5.53	1.73	7.54	1.79	12.38	3.48	2.39	0.90
Winter/Year [%]	-	31.3	-	23.8	-	28.2	-	37.7