



*Supplement of*

## **Leaching of inorganic and organic phosphorus and nitrogen in contrasting beech forest soils – seasonal patterns and effects of fertilization**

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# Supplementary information

## SI 1: Site properties

Table S1: Characteristics of the two study sites Bad Brückenau (BBR, high-P) und Lüss (LUE, low-P), data from Lang et al. 2017, and personal communication J. Krüger.

	High-P site	Low-P site
Location	N: 50.351800° E: 09.927478°	N: 52.838967° E: 10.267250°
Elevation (m a.s.l.)	809	115
Slope / aspect	10° ± 3° / distributed at a shallow hilltop	No slope / -
Mean annual temperature (°C)	5.8	8.0
Mean annual precipitation (mm)	1031	779
Forest stand	Beech ( <i>Fagus sylvatica</i> (99) <i>Acer Pseudoplatanus</i> )	Beech ( <i>Fagus sylvatica</i> (91) <i>Quercus petraea</i> (9))
Parent material	basalt	sandy till
Cation exchange capacity (meq (kg <sup>-1</sup> ))	371	108
Fe <sub>ox</sub> and Al <sub>ox</sub> (g kg <sup>-1</sup> ) in Ah	29.3 and 8.4	0.9 and 0.3
Soil type	dystric skeletal Cambisol (hyperhumic, loamic)	hyperdystric folic Cambisol (arenic, loamic, nechic, protosodic)
pH (CaCl <sub>2</sub> ) at 0-5 cm	3.2	3.0
Humus layer	mull-like moder	mor-like moder

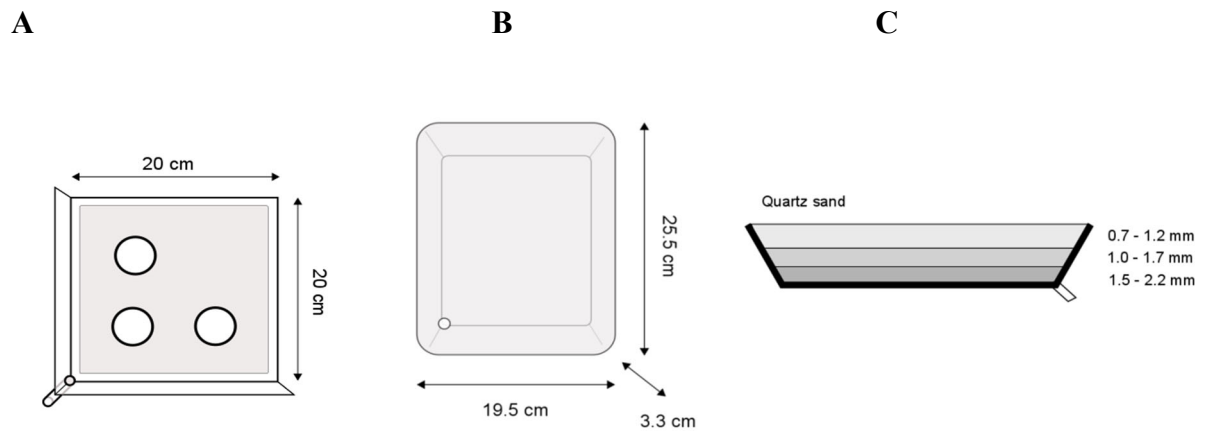
**SI 2: Lysimeter design**

Figure S1: Zero-tension lysimeter design. (A) Type 1 lysimeter for the litter and Oe/Oa horizon, (B) Type 2 lysimeter for the mineral topsoil, (C) Type 2 lysimeter showing the filling with different grained quartz sand.

### SI 3: Q<sub>10</sub> values

Table S2: Estimated Q<sub>10</sub> of nutrient concentrations as expressed with the Q<sub>10</sub> value for total dissolved phosphorus (TDP), dissolved inorganic P (DIP), dissolved organic P (DOP), total dissolved nitrogen (TDN), dissolved inorganic N (DIN), and dissolved organic N (DON) for the litter layer, Oe/Oa horizon, and A horizon at the high-P site (Bad Brückenau, BBR) and the low-P site (Lüss, LUE). Exponential fitting was done for every site and horizon separately, summing up to 20 data points for each fitting: 5 seasons \* 4 treatments.

Site	Horizon	TDP_av				DIP_av				DOP_av				
		n = 20 *	Q <sub>10</sub>	R <sup>2</sup>	F value	p	Q <sub>10</sub>	R <sup>2</sup>	F value	p	Q <sub>10</sub>	R <sup>2</sup>	F value	p
High-P	Litter		4.1	0.76	56.97	<0.001	6.1	0.69	40.68	<0.001	2.1	0.70	41.84	<0.001
High-P	Oe/Oa horizon		3.5	0.61	28.52	<0.001	5.6	0.61	28.40	<0.001	1.6	0.26	6.41	0.021
High-P	A horizon		3.6	0.67	36.25	<0.001	5.0	0.66	34.66	<0.001	1.9	0.51	18.86	<0.001
Low-P	Litter		3.4	0.51	18.79	<0.001	4.2	0.50	17.73	0.001	1.8	0.31	7.92	0.012
Low-P	Oe/Oa horizon		2.1	0.17	3.71	0.070	2.4	0.17	3.68	0.071	1.6	0.27	6.66	0.019
Low-P	A horizon		2.6	0.26	6.40	0.021	2.9	0.24	5.80	0.027	2.0	0.30	7.75	0.012

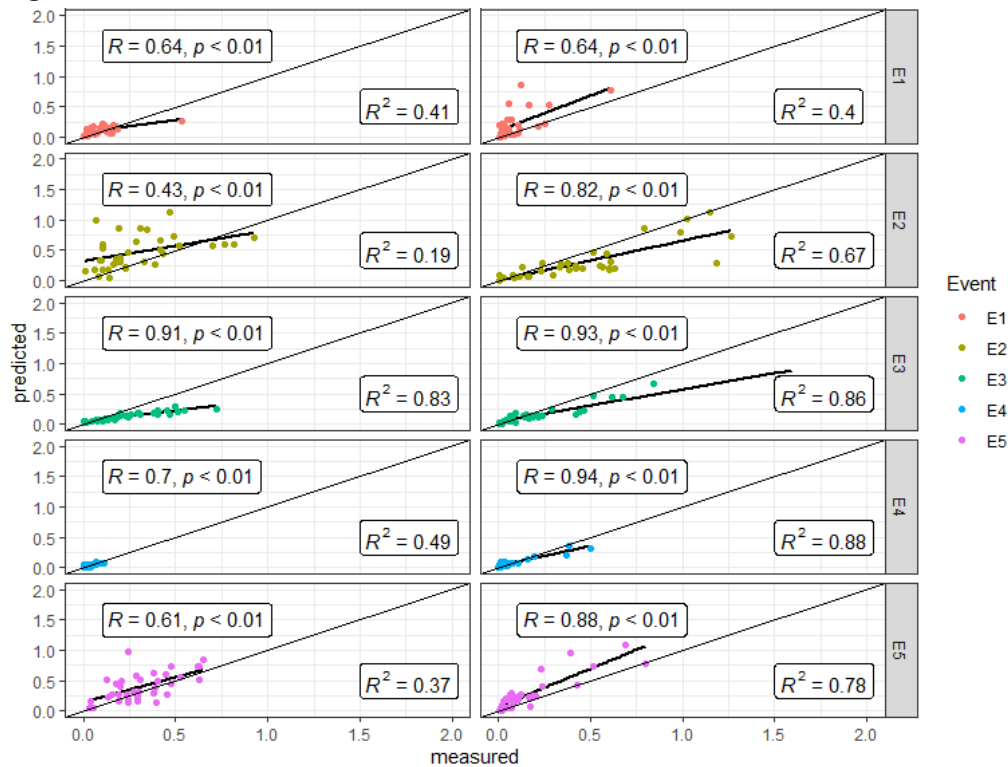
Site	Horizon	TDN_av				DIN_av				DON_av				DOC_av				
		n = 20 *	Q <sub>10</sub>	R <sup>2</sup>	F value	p	Q <sub>10</sub>	R <sup>2</sup>	F value	p	Q <sub>10</sub>	R <sup>2</sup>	F value	p	Q <sub>10</sub>	R <sup>2</sup>	F value	p
High-P	Litter		3.6	0.35	9.86	0.006	4.1	0.25	6.10	0.024	3.6	0.37	10.60	0.004	2.1	0.47	16.08	0.001
High-P	Oe/Oa horizon		3.9	0.58	24.71	<0.001	4.3	0.47	15.91	0.001	4.9	0.20	4.58	0.046	2.2	0.52	19.29	<0.001
High-P	A horizon		1.9	0.17	3.68	0.071	2.2	0.16	3.41	0.081	1.8	0.20	4.49	0.048	1.2	0.04	0.76	0.396
Low-P	Litter		3.9	0.52	19.44	<0.001	3.5	0.42	12.96	0.002	4.8	0.57	23.99	<0.001	2.1	0.65	33.27	<0.001
Low-P	Oe/Oa horizon		2.6	0.30	7.81	0.012	3.0	0.22	5.02	0.038	2.1	0.33	8.75	0.008	1.3	0.09	1.85	0.191
Low-P	A horizon		2.2	0.23	5.29	0.034	2.0	0.12	2.34	0.143	2.2	0.42	13.08	0.002	1.4	0.12	2.41	0.138

## SI 4: Measured vs. predicted nutrient concentrations

### Dissolved inorganic phosphorus (DIP) concentration

#### High-P site

#### Low-P site



### Dissolved organic phosphorus (DOP) concentration

#### High-P site

#### Low-P site

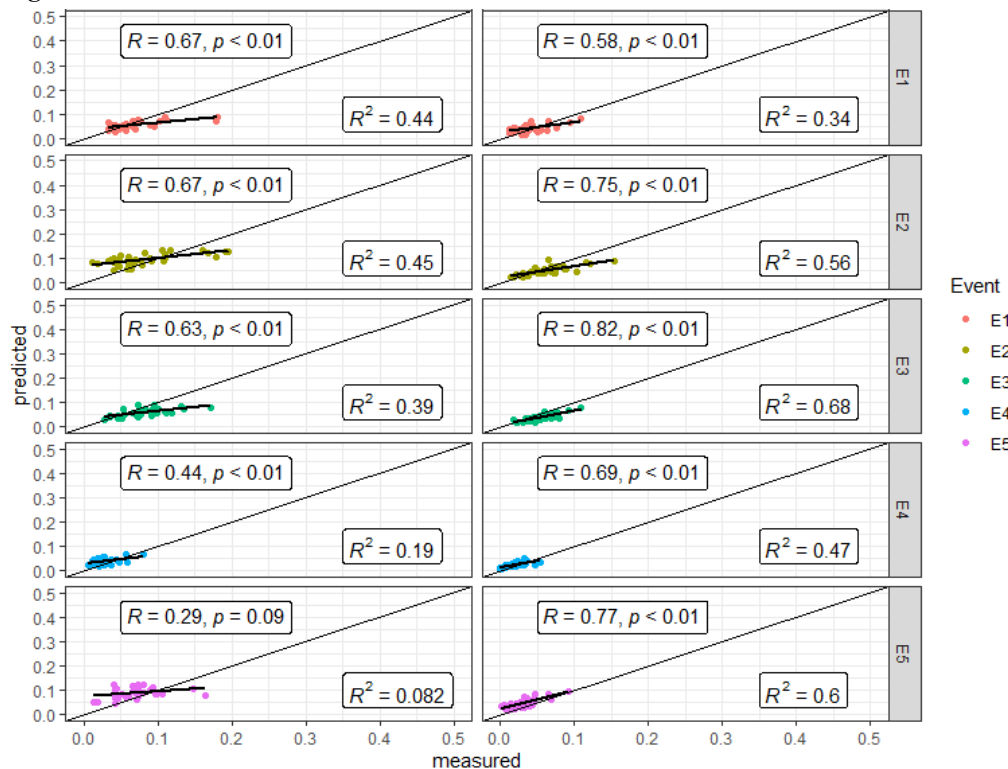


Figure S2: Predicted vs. measured nutrient concentrations. Predicted nutrient concentrations are based on estimated  $Q_{10}$  values with exponential fitting. Pearson correlation and p-value,  $R^2$ . E1: April 2018, E2: July 2018, E3: October 2018, E4: February/March 2019, E5: July 2019.

## SI 5: Statistic for concentrations, flux data, and nutrient ratios

### Concentration data:

Table S3: Statistical output of linear mixed effect model for concentration data. TP = total dissolved phosphorus; DOP = dissolved organic phosphorus; DOC = dissolved organic carbon; TN = total dissolved nitrogen; DIN = dissolved inorganic nitrogen; DON = Dissolved organic nitrogen.

```
d.lmer <- lmer(d2$Ptot_log ~ Site * N * P + Event * Horizon + (1|Block/Plot/Subplot), REML = T, na.action = na.exclude, data = d2)
```

	TP_log				DOP_log				PO4.P_log				DOC_log			
	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.
Site	1	0.7	0.46		1	0.2	0.65		1	19.1	0.01	**	1	88	<0.01	***
N	1	0.1	0.76		1	0.1	0.79		1	0	0.93		1	1	0.33	
P	1	5.2	0.04	**	1	6.7	0.02	**	1	1.6	0.23		1	0.2	0.65	
Season (Event)	4	94.3	<0.01	***	4	84.8	<0.01	***	4	62.5	<0.01	***	4	36	<0.01	***
Horizon	2	14.5	<0.01	***	2	13.4	<0.01	***	2	10.2	<0.01	***	2	41.8	<0.01	***
Site:N	1	0	0.86		1	0.2	0.70		1	0	0.90		1	3.1	0.10	
Site:P	1	0	0.93		1	0.2	0.69		1	0.6	0.45		1	0.3	0.59	
N:P	1	2.2	0.17		1	1.6	0.23		1	1.8	0.21		1	7.3	0.02	**
Season: Horizon	8	2.4	0.02	**	8	2.5	0.01	**	8	1.9	0.07	*	8	3.3	<0.01	***
Site:N:P	1	5.4	0.04	**	1	4.9	0.05	*	1	2.7	0.12		1	4.4	0.05	*

	TN_log				DIN_log				DON_log				pH_log			
	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.
Site	1	0.1	0.81		1	0	0.95		1	0	0.92		1	5.6	0.08	*
N	1	11.2	<0.01	***	1	13.4	<0.01	***	1	6	0.03	**	1	22.6	<0.01	***
P	1	0.1	0.73		1	0	0.83		1	0	0.98		1	0	0.90	
Season (Event)	4	53.5	<0.01	***	4	69.8	<0.01	***	4	46.2	<0.01	***	4	64.9	<0.01	***
Horizon	2	11.7	<0.01	***	2	3.6	0.04	**	2	10.3	<0.01	***	2	8.6	<0.01	***
Site:N	1	0	0.96		1	0.4	0.55		1	1.4	0.25		1	0	0.86	
Site:P	1	1	0.35		1	2	0.18		1	0.5	0.49		1	0.3	0.57	
N:P	1	1	0.34		1	0.8	0.39		1	0.8	0.38		1	2.6	0.14	
Season: Horizon	8	4.3	<0.01	***	8	8.2	<0.01	***	8	2.2	0.03	**	8	1.9	0.05	*
Site:N:P	1	0.8	0.39		1	0	0.91		1	0.1	0.75		1	0	0.90	

**Flux data:**

Table S4: Statistical output of linear mixed effect models for flux data. TP = total dissolved phosphorus; DOP = dissolved organic phosphorus; DOC = dissolved organic carbon; TN = total dissolved nitrogen; DIN = dissolved inorganic nitrogen; DON = Dissolved organic nitrogen.

```
d.lmer <- lmer(TP_log ~ Site * N * P + Horizon +(1|Block/Plot), na.action = na.exclude, data = d2)
```

All	TP_log				DOP_log				PO4.P_log				DOC_log			
	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.
Site	1	2.1	0.22		1	45.3	<0.01	***	1	1.0	0.37		1	6.2	0.02	**
N	1	0.4	0.54		1	0.0	0.95		1	0.3	0.60		1	0.8	0.38	
P	1	2.4	0.14		1	0.2	0.66		1	4.1	0.07	*	1	0.5	0.48	
Horizon	2	29.8	<0.01	***	2	35.4	<0.01	***	2	25.6	<0.01	***	2	19.4	<0.01	***
Site:N	1	0.2	0.66		1	0.0	0.85		1	0.6	0.47		1	4.5	0.05	*
Site:P	1	1.4	0.26		1	0.0	1.00		1	2.0	0.18		1	0.0	0.89	
N:P	1	1.4	0.26		1	0.6	0.47		1	1.0	0.33		1	2.9	0.11	
Site:N:P	1	4.9	0.05	*	1	1.5	0.24		1	4.1	0.07	*	1	2.9	0.11	

All	TN_log				NH4.N_log				NO3.N_log				DON_log			
	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.
Site	1	2.0	0.23		1	0.0	0.94		1	3.9	0.12		1	4.9	0.09	*
N	1	10.9	<0.01	***	1	11.8	<0.01	***	1	10	<0.01	**	1	9.1	0.01	**
P	1	0.8	0.40		1	2.6	0.13		1	0.5	0.51		1	0.4	0.56	
Horizon	2	5.0	0.01	**	2	4.3	0.02	**	2	0.8	0.45		2	13.3	<0.01	***
Site:N	1	0.1	0.79		1	0.1	0.72		1	1.8	0.21		1	0.9	0.36	
Site:P	1	1.5	0.25		1	1.6	0.22		1	1.1	0.31		1	1.4	0.25	
N:P	1	0.3	0.62		1	0.3	0.61		1	0.0	0.94		1	0.7	0.42	
Site:N:P	1	0.2	0.68		1	0.1	0.82		1	0.0	0.94		1	1.1	0.31	

**Nutrient ratios:**

Table S5: Statistical output of linear mixed effect models for nutrient ratios in the leachate. TDP = total dissolved phosphorus; DOP = dissolved organic phosphorus; DIP = dissolved inorganic phosphorus; sDOC = dissolved organic carbon; TDN = total dissolved nitrogen; DIN = dissolved inorganic nitrogen; DON = Dissolved organic nitrogen.

d.lmer <- lmer(d2\$Ptot\_log ~ Site \* N \* P \* Event \* Horizon + (1 |Block/Plot/Subplot), REML = T, na.action = na.exclude, data = d2)

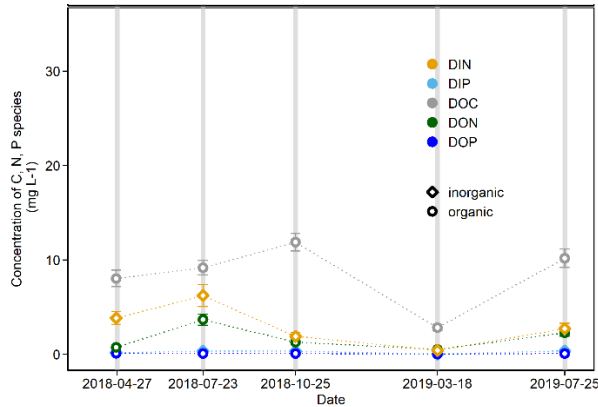
	DOC.DON_log				DOC.DOP_log				DON.DOP_log				DIN.DIP_log			
	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.
Site	1	14.5	0.02 **		1	127.7	<0.01 ***		1	20.7	<0.01 ***		1	3.7	0.07 *	
N	1	18.3	<0.01 ***		1	0.1	0.74		1	11.2	<0.01 ***		1	15.5	<0.01 ***	
P	1	0	0.87		1	2.1	0.17		1	1.1	0.30		1	7.4	0.02 **	
Season (Event)	4	63.2	<0.01 ***		4	21.4	<0.01 ***		4	26.5	<0.01 ***		4	28.8	<0.01 ***	
Horizon	2	14.5	<0.01 ***		2	64.7	<0.01 ***		2	15.7	<0.01 ***		2	4.9	0.01 **	
Site:N	1	0	0.99		1	3.9	0.07 *		1	0.8	0.38		1	1.1	0.31	
Site:P	1	2.5	0.14		1	0.1	0.80		1	4	0.06 *		1	1.3	0.28	
N:P	1	0.1	0.75		1	0.5	0.49		1	0.3	0.59		1	0.1	0.79	
Site:Season	4	30.6	<0.01 ***		4	22.9	<0.01 ***		4	5	<0.01 ***		4	7.8	<0.01 ***	
N:Event	4	6.1	<0.01 ***		4	2.4	0.05		4	3.8	<0.01 ***		4	2.2	0.07 *	
P:Event	4	1	0.43		4	1.3	0.27		4	0.7	0.59		4	4.1	<0.01 ***	
Site:Horizon	2	9	<0.01 ***		2	12.3	<0.01 ***		2	0.7	0.52		2	2.2	0.13	
N:Horizon	2	0.7	0.50		2	2.5	0.08 *		2	0.3	0.74		2	0.3	0.74	
P:Horizon	2	0.2	0.81		2	0.2	0.79		2	0.2	0.82		2	1.3	0.29	
Event:Horizon	8	3	<0.01 ***		8	3.4	<0.01 ***		8	2.9	<0.01 ***		8	3.2	<0.01 ***	
Site:N:P	1	0	0.90		1	0	0.91		1	0.6	0.44		1	3.5	0.08 *	
Site:N:Event	4	1.5	0.21		4	3.6	<0.01 ***		4	2.9	0.02 **		4	0.9	0.44	
Site:P:Horizon	2	1.1	0.33		2	0.9	0.41		2	4	0.03 **		2	0.1	0.93	
Site:Event:Horizon	8	1.4	0.19		8	5.2	<0.01 ***		8	6.1	<0.01 ***		8	4.2	<0.01 ***	
Site:N:P:Event	4	1.4	0.22		4	1	0.40		4	2	0.09 *		4	0.2	0.95	

	DOC.TDN_log				DOC.TDP_log				TDN.TDP_log			
	DF	F value	p value	Sign.	DF	F value	p value	Sign.	DF	F value	p value	Sign.
Site	1	3.9	0.12		1	4.8	0.09	*	1	4.8	0.09	*
N	1	20.9	<0.01	***	1	0	0.95		1	13.3	<0.01	***
P	1	0.3	0.60		1	8.3	0.01	**	1	6.8	0.02	**
Event	4	43.7	<0.01	***	4	41.4	<0.01	***	4	18.3	<0.01	***
Horizon	2	8.6	<0.01	***	2	44.3	<0.01	***	2	16.6	<0.01	***
Site:N	1	1.1	0.33		1	0.7	0.43		1	0.1	0.73	
Site:P	1	4.2	0.06	*	1	0.2	0.63		1	2	0.19	
N:P	1	0.1	0.77		1	0.1	0.74		1	0	0.99	
Site:Event	4	34.1	<0.01	***	4	17.7	<0.01	***	4	6.6	<0.01	***
N:Event	4	7.7	<0.01	***	4	0.9	0.49		4	6.8	<0.01	***
P:Event	4	1.1	0.34		4	1	0.40		4	2.3	0.06	*
Site:Horizon	2	13.8	<0.01	***	2	13	<0.01	***	2	0	0.96	
N:Horizon	2	0.4	0.71		2	0.6	0.56		2	0.2	0.83	
P:Horizon	2	1.5	0.24		2	2.7	0.08	*	2	0.1	0.90	
Event:Horizon	8	6.9	<0.01	***	8	2.6	0.01	**	8	2.7	<0.01	***
Site:N:P	1	0	0.92		1	2.7	0.13		1	0.7	0.41	
Site:N:Event	4	3.1	0.02	**	4	1.2	0.29		4	2.3	0.06	*
Site:P:Horizon	2	0.1	0.91		2	1.1	0.35		2	0.5	0.60	
Site:Event:Horizon	8	1.7	0.10		8	3.1	<0.01	***	8	5.4	<0.01	***



## SI 6: Dissolved organic carbon (DOC) seasonal pattern and annual fluxes

(A) High-P site – Oe/Oa horizon



(B) Low-P site – Oe/Oa horizon

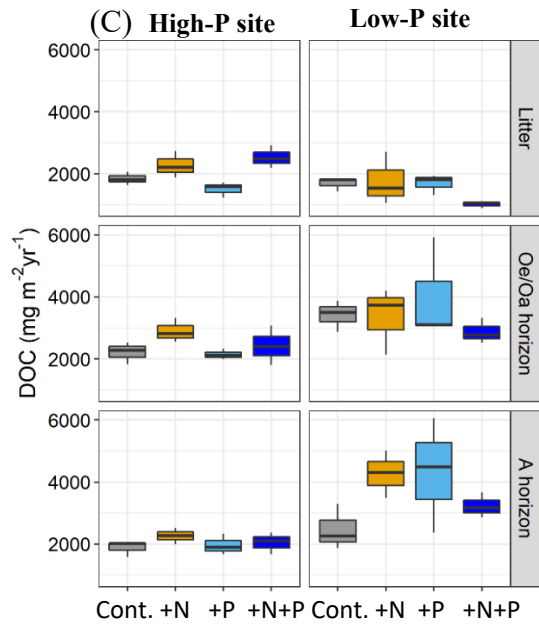
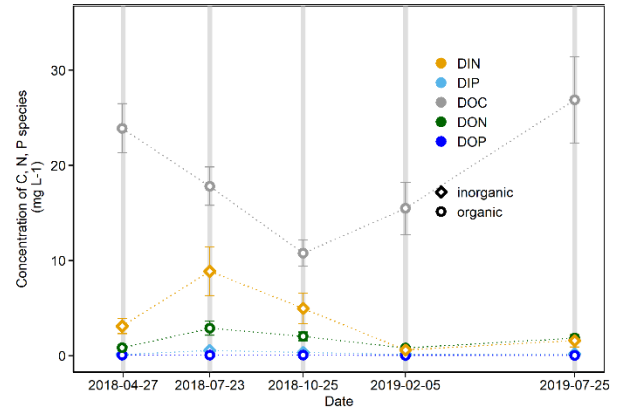


Figure S3: A and B: Concentration of organic and inorganic nitrogen (N), phosphorus (P), and carbon (C) forms during the experimental duration at the high-P site (A) and the low-P site (B) in leachates from the litter horizon, the Oe/Oa horizon, and the A horizon (including fertilization treatments,  $n = 12$ ). C: Estimated annual fluxes of dissolved organic carbon (DOC) in the litter, the Oe/Oa horizon, and the A horizon at the high-P site and the low-P site as affected by fertilization with N and P. Annual flux estimated for July 2018 to July 2019.

Table S6: Comparison of dissolved organic carbon (DOC) fluxes from litter, Oe/Oa horizon, and A horizon with respective stocks (from July 2019) in the horizons at the high-P site and the low-P site. Net flux: the difference between the fluxes into and out of a given horizon; positive values reflect net accumulations, negative numbers net losses. Data from unfertilized plots ( $n = 3$ ). SE = Standard error.

Site	Horizon	Horizon thickness cm	C stock of control g C m <sup>-2</sup>	C flux of control g m <sup>-2</sup> yr <sup>-1</sup> ± SE	Annual DOC flux	DOC balances
					to stock % yr <sup>-1</sup>	mg C m <sup>-2</sup>
High-P	Litter	2	135	1.838 ± 0.099	1.36	
High-P	Oe/Oa	2.5	703	2.214 ± 0.167	0.31	-377
High-P	A	5	3553	1.876 ± 0.120	0.05	+338
Low-P	Litter	4.5	313	1.688 ± 0.105	0.54	
Low-P	Oe/Oa	6	2760	3.411 ± 0.234	0.12	-1723
Low-P	A	5	2613	2.469 ± 0.348	0.09	+942

## SI 7: Annual vertical water fluxes

Table S7: Measured vertical water fluxes as bulk samples between the point sampling campaigns due to natural rain events. Presented are a mean value per site and horizon as well as a maximum value. As comparison, the modeled fluxes from the ICP Forest Level II sites are presented. The fluxes shown here once exclude the water volume of the artificial irrigation and once including this volume. BBR = Bad Brückenau, LUE = Unterlüss. P = phosphorus.

Site	Horizon	Art. Irr. vol.***	Jul-Oct'18		Art. Irr. vol.** *	Oct19-Feb/Mar'19		Art. Irr. vol.***	FebMar19-Jul'19		Art. Irr. vol.** *	SUM w/o art. Irrigation		SUM incl. art. Irrigation		
			July '18	mean	max.	Oct '18	mean	max.	Feb/Mar '18	mean	max.	July '19	mean	max.	mean	max.
BBR - ICP Forest site	High-P	measured throughfall			75		403			245		722	722	722	722	
BBR	High-P	Litter	9.69	47	80	16	199	226	7	111	174	12	357	480	402	525
BBR	High-P	Oe/Oa horizon	12.16	53	71	13	160	234	6	96	157	13	309	462	353	507
BBR	High-P	A horizon	8.16	42	60	11	107	177	7	76	135	12	226	373	264	411
BBR - ICP forest site*	High-P	Vertical matrix flow modeled av. 5-6 cm			51			395			137			583		583
BBR - ICP forest site*	High-P	Vertical matrix flow modeled av. 1-5 cm			27			387			139			553		553
BBR - ICP forest site*	High-P	Vertical matrix flow modeled -5 cm			0			364			125			489		489
LUE - ICP forest site	Low-P	measured throughfall			56			124			184		364	364	364	364
LUE	Low-P	Litter (thickness on av.: 1.5 cm)	14.94	32	42	12	48	65	12	76	86	13	156	192	208	244
LUE	Low-P	Oe/Oa horizon (thickness on av.: 1 cm)	12.69	40	51	13	50	70	11	53	62	19	143	183	198	239
LUE	Low-P	A horizon (thickness on av.: 1.5 cm)	12.99	16	23	12	41	47	13	47	85	17	103	154	159	210
LUE - ICP forest site*	Low-P	Vertical water flow modeled at 0 m			7			150			91			249**		249***
LUE - ICP forest site*	Low-P	Vertical water flow modeled at 0.2 m			5			147			82			233**		233***

\* modeled with LWF-Brook90(R) model

\*\* time period: modeled only until 14.07.2019

\*\*\* average, n = 12

## SI 8: Stoichiometry of leachate compounds and soil

Table S8: Soil carbon (C), nitrogen (N), and phosphorus (P) contents and ratios and for comparison, critical threshold values from Heuck and Spohn, 2016. None of our values is above the critical threshold determined by Heuck and Spohn – mineralization in these horizons at both sites is NOT inhibited by nutrient limitation.

Site	Horizon	Treatment	total soil C		total soil N		total soil P		Resin extractable P*		soil C:N		Soil N:P		Soil C:P		
			mg g <sup>-1</sup> ± SE		mg g <sup>-1</sup>		mg g <sup>-1</sup> ± SE		mg g <sup>-1</sup> ± SE		- ± SE		- ± SE		- ± SE		
n=15																	
High-P	Litter	Control	451	± 0.7	17.0	± 0.02	0.96	± 0.04	NA	± NA	26	± 0.0	18	± 0.7	468	± 17.4	
High-P	Litter	+N	451	± 1.0	16.7	± 0.60	0.88	± 0.02	NA	± NA	27	± 1.0	19	± 0.8	514	± 13.8	
High-P	Litter	+P	444	± 2.1	17.3	± 0.23	1.20	± 0.04	NA	± NA	26	± 0.4	14	± 0.4	369	± 10.4	
High-P	Litter	+N+P	456	± 0.4	16.7	± 0.24	0.99	± 0.03	NA	± NA	27	± 0.4	17	± 0.5	459	± 12.3	
Low-P	Litter	Control	391	± 4.1	14.9	± 0.15	0.79	± 0.03	NA	± NA	26	± 0.5	19	± 0.8	495	± 28.9	
Low-P	Litter	+N	423	± 3.2	16.7	± 0.44	0.79	± 0.03	NA	± NA	25	± 0.4	21	± 0.8	535	± 23.9	
Low-P	Litter	+P	426	± 1.8	16.7	± 0.40	1.05	± 0.07	NA	± NA	26	± 0.5	16	± 0.8	408	± 27.2	
Low-P	Litter	+N+P	382	± 12	15.2	± 0.47	0.78	± 0.04	NA	± NA	25	± 0.4	19	± 0.7	486	± 25.4	
High-P	Oe/Oa horizon	Control	352	± 7.7	19.4	± 0.15	2.30	± 0.15	0.149	± 0.011	18	± 0.3	8.4	± 0.7	153	± 15.5	
High-P	Oe/Oa horizon	+N	320	± 6.1	17.8	± 0.33	2.17	± 0.04	0.126	± 0.005	18	± 0.1	8.2	± 0.1	147	± 2.63	
High-P	Oe/Oa horizon	+P	361	± 3.1	19.6	± 0.12	1.54	± 0.21	0.174	± 0.004	18	± 0.1	13	± 3.7	234	± 68.0	
High-P	Oe/Oa horizon	+N+P	311	± 11	18.2	± 0.54	2.37	± 0.12	0.131	± 0.008	17	± 0.2	7.7	± 0.7	132	± 12.9	
Low-P	Oe/Oa horizon	Control	316	± 7.4	11.8	± 0.67	0.53	± 0.04	0.085	± 0.006	27	± 1.4	22	± 0.3	597	± 38.9	
Low-P	Oe/Oa horizon	+N	264	± 23	13.7	± 1.26	0.52	± 0.06	0.074	± 0.004	19	± 0.2	26	± 1.9	506	± 29.7	
Low-P	Oe/Oa horizon	+P	240	± 18	14.7	± 0.83	0.68	± 0.02	0.125	± 0.006	16	± 1.1	22	± 0.5	354	± 19.7	
Low-P	Oe/Oa horizon	N+P	216	± 16	15.9	± 0.34	0.68	± 0.02	0.095	± 0.002	14	± 0.7	24	± 0.4	319	± 14.1	
High-P	A horizon	Control	178	± 9.5	12.0	± 0.60	3.02	± 0.13	0.040	± 0.005	15	± 0.2	4.0	± 0.1	59	± 1.9	
High-P	A horizon	+N	146	± 5.6	10.5	± 0.25	3.02	± 0.13	0.029	± 0.001	14	± 0.2	3.5	± 0.2	48	± 4.2	
High-P	A horizon	+P	157	± 10	10.7	± 0.53	2.94	± 0.16	0.057	± 0.003	15	± 0.3	3.6	± 0.1	54	± 2.7	
High-P	A horizon	+N+P	172	± 10	11.8	± 0.57	2.89	± 0.06	0.029	± 0.001	15	± 0.1	4.1	± 0.2	59	± 3.0	
Low-P	A horizon	Control	69.7	± 6.3	3.42	± 0.30	0.17	± 0.01	0.002	± 0.000	20	± 0.1	20	± 0.8	412	± 18.1	
Low-P	A horizon	+N	173	± 33	2.94	± 0.27	0.19	± 0.01	0.004	± 0.000	59	± 16	15	± 2.6	897	± 162	
Low-P	A horizon	+P	87.1	± 5.8	3.98	± 0.24	0.20	± 0.01	0.009	± 0.001	22	± 0.2	20	± 0.7	443	± 19.5	
Low-P	A horizon	+N+P	65.2	± 4.4	3.02	± 0.22	0.17	± 0.01	0.006	± 0.000	22	± 0.6	18	± 0.8	379	± 17.0	

High-P	Litter	Heuck et al. 2016	431	18	1.66	24	11	259	
High-P	Oe	Heuck et al. 2016	333	15.5	1.67	21	9	199	
High-P	Oa	Heuck et al. 2016	-	-	-	-	-	-	
Low-P	Litter	Heuck et al. 2016	422	17.1	1.24	25	14	340	
Low-P	Oe	Heuck et al. 2016	392	15.6	0.95	25	16	413	
Low-P	Oa	Heuck et al. 2016	358	15.1	0.56	24	27	639	
Net mineralization rate N Oi						(Heuck and Spohn, 2016)- crit. threshold ratios**	40	42	
Net mineralization rate P Oi						(Heuck and Spohn, 2016)- crit. threshold ratios**			1400
Net mineralization rate N Oa						(Heuck and Spohn, 2016)- crit. threshold ratios**	28	60	

Table S9: Dissolved organic, inorganic, and total carbon (DOC), nitrogen (DON, DIN, TDN), and phosphorus (DOP, DIP, TDP) concentrations in leachates.

Site	Horizon	Treatment	Leachate TDP		Leachate DIP		Leachate DOP		Leachate TDN		Leachate DIN		Leachate DON		Leachate DOC	
			mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE	mg L <sup>-1</sup> ± SE			
High-P	Litter	Control	0.16 ± 0.03	0.09 ± 0.03	0.06 ± 0.01	1.29 ± 0.26	0.73 ± 0.19	0.56 ± 0.10	5.37 ± 0.90							
High-P	Litter	+N	0.17 ± 0.05	0.11 ± 0.04	0.06 ± 0.01	3.14 ± 0.98	2.20 ± 0.88	0.95 ± 0.25	6.85 ± 0.88							
High-P	Litter	+P	0.19 ± 0.03	0.13 ± 0.03	0.06 ± 0.01	1.75 ± 0.59	1.06 ± 0.36	0.70 ± 0.23	4.62 ± 0.47							
High-P	Litter	+N+P	0.35 ± 0.07	0.28 ± 0.06	0.07 ± 0.01	3.85 ± 0.83	2.33 ± 0.51	1.52 ± 0.36	7.73 ± 1.31							
Low-P	Litter	Control	0.13 ± 0.04	0.10 ± 0.03	0.03 ± 0.01	1.91 ± 0.52	0.97 ± 0.22	0.93 ± 0.31	6.81 ± 0.99							
Low-P	Litter	+N	0.20 ± 0.05	0.16 ± 0.04	0.04 ± 0.01	6.09 ± 1.92	4.53 ± 1.48	1.56 ± 0.45	8.97 ± 1.10							
Low-P	Litter	+P	0.29 ± 0.07	0.24 ± 0.06	0.05 ± 0.01	1.88 ± 0.42	1.14 ± 0.29	0.74 ± 0.14	8.83 ± 0.78							
Low-P	Litter	+N+P	0.19 ± 0.05	0.14 ± 0.04	0.06 ± 0.02	3.06 ± 0.67	2.70 ± 0.82	0.86 ± 0.21	5.22 ± 0.59							
High-P	Oe/Oa horizon	Control	0.22 ± 0.04	0.15 ± 0.03	0.07 ± 0.01	2.60 ± 0.67	1.71 ± 0.48	0.90 ± 0.22	7.68 ± 1.31							
High-P	Oe/Oa horizon	+N	0.28 ± 0.05	0.20 ± 0.04	0.08 ± 0.01	5.67 ± 1.17	3.90 ± 0.78	2.02 ± 0.49	9.64 ± 1.19							
High-P	Oe/Oa horizon	+P	0.32 ± 0.05	0.24 ± 0.05	0.08 ± 0.01	2.91 ± 0.53	1.93 ± 0.34	0.98 ± 0.22	7.01 ± 0.73							
High-P	Oe/Oa horizon	+N+P	0.36 ± 0.06	0.29 ± 0.05	0.08 ± 0.01	4.71 ± 0.96	3.06 ± 0.75	1.65 ± 0.33	8.09 ± 1.05							
Low-P	Oe/Oa horizon	Control	0.14 ± 0.04	0.11 ± 0.03	0.03 ± 0.00	3.07 ± 0.94	1.94 ± 0.68	1.13 ± 0.29	18.45 ± 2.32							
Low-P	Oe/Oa horizon	+N	0.44 ± 0.13	0.39 ± 0.13	0.05 ± 0.01	13.23 ± 4.25	6.38 ± 1.60	1.77 ± 0.43	17.16 ± 2.05							
Low-P	Oe/Oa horizon	+P	0.40 ± 0.08	0.34 ± 0.07	0.05 ± 0.01	4.18 ± 0.94	2.51 ± 0.75	1.68 ± 0.27	27.38 ± 4.63							
Low-P	Oe/Oa horizon	+N+P	0.17 ± 0.05	0.14 ± 0.05	0.04 ± 0.01	6.08 ± 2.89	4.38 ± 2.24	1.70 ± 0.67	14.98 ± 1.55							
High-P	A horizon	Control	0.29 ± 0.11	0.23 ± 0.11	0.06 ± 0.01	3.27 ± 0.57	2.09 ± 0.38	1.17 ± 0.28	9.94 ± 2.20							
High-P	A horizon	+N	0.13 ± 0.03	0.08 ± 0.03	0.05 ± 0.01	4.13 ± 0.84	2.63 ± 0.54	1.51 ± 0.35	9.08 ± 1.18							
High-P	A horizon	+P	0.19 ± 0.03	0.14 ± 0.03	0.06 ± 0.01	2.67 ± 0.41	1.86 ± 0.36	0.81 ± 0.11	8.37 ± 0.96							
High-P	A horizon	+N+P	0.22 ± 0.05	0.17 ± 0.04	0.05 ± 0.01	5.47 ± 2.15	3.70 ± 1.50	1.78 ± 0.66	8.43 ± 1.29							
Low-P	A horizon	Control	0.09 ± 0.03	0.06 ± 0.03	0.02 ± 0.00	1.99 ± 0.43	1.37 ± 0.33	0.62 ± 0.11	12.68 ± 1.68							
Low-P	A horizon	+N	0.21 ± 0.07	0.18 ± 0.06	0.03 ± 0.00	7.01 ± 1.46	5.29 ± 1.13	1.73 ± 0.35	21.31 ± 2.56							
Low-P	A horizon	+P	0.23 ± 0.07	0.19 ± 0.06	0.04 ± 0.01	2.62 ± 0.73	1.66 ± 0.58	0.95 ± 0.20	21.19 ± 3.23							
Low-P	A horizon	+N+P	0.13 ± 0.03	0.10 ± 0.03	0.03 ± 0.00	5.23 ± 1.91	3.95 ± 1.56	1.28 ± 0.37	17.00 ± 2.04							

Table S10: Dissolved organic, inorganic, and total carbon (DOC), nitrogen (DON, DIN, TDN), and phosphorus (DOP, DIP, TDP) ratios in leachates.

Site	Horizon	Treatment	Leachate DOC:DON	Leachate DOC:DOP	Leachate DON:DOP	Leachate DOC:TDN	Leachate DOC:TDP	Leachate TDN:TDP	Leachate DIN:DIP
			-	-	-	-	-	-	-
High-P	Litter	Control	9.6	85.3	8.9	4.2	34.6	8.3	7.9
High-P	Litter	+N	7.2	118.1	16.4	2.2	41.5	19.0	20.5
High-P	Litter	+P	6.6	83.4	12.6	2.6	24.9	9.4	8.2
High-P	Litter	+N+P	5.1	110.6	21.7	2.0	22.2	11.1	8.4
Low-P	Litter	Control	7.3	207.9	28.5	3.6	52.7	14.8	10.1
Low-P	Litter	+N	5.8	222.9	38.7	1.5	45.4	30.8	28.7
Low-P	Litter	+P	11.9	163.4	13.7	4.7	30.3	6.5	4.8
Low-P	Litter	+N+P	6.0	91.2	15.1	1.7	28.1	16.5	18.9
High-P	Oe/Oa horizon	Control	8.6	117.8	13.8	2.9	35.0	11.9	11.1
High-P	Oe/Oa horizon	+N	4.8	123.4	25.8	1.7	34.8	20.4	19.6
High-P	Oe/Oa horizon	+P	7.1	90.0	12.6	2.4	21.9	9.1	8.0
High-P	Oe/Oa horizon	+N+P	4.9	105.4	21.5	1.7	22.3	13.0	10.7
Low-P	Oe/Oa horizon	Control	16.4	604.6	36.9	6.0	135.9	22.6	18.5
Low-P	Oe/Oa horizon	+N	9.7	346.5	35.7	1.3	39.3	30.3	16.5
Low-P	Oe/Oa horizon	+P	16.3	536.2	32.8	6.5	69.2	10.6	7.3
Low-P	Oe/Oa horizon	+N+P	8.8	377.7	42.7	2.5	85.6	34.7	32.0
High-P	A horizon	Control	8.5	154.7	18.3	3.0	34.0	11.2	9.2
High-P	A horizon	+N	6.0	187.5	31.1	2.2	70.1	31.9	32.4
High-P	A horizon	+P	10.3	145.8	14.2	3.1	43.4	13.9	13.7
High-P	A horizon	+N+P	4.7	155.7	32.8	1.5	37.9	24.7	22.0
Low-P	A horizon	Control	20.5	513.9	25.1	6.4	147.9	23.2	22.2
Low-P	A horizon	+N	12.3	677.8	54.9	3.0	99.3	32.7	28.9
Low-P	A horizon	+P	22.2	529.2	23.8	8.1	93.4	11.5	8.9
Low-P	A horizon	+N+P	13.3	495.7	37.2	3.3	128.7	39.6	40.4

**SI S9: Stoichiometry graphs: nutrients in soil versus leachate**

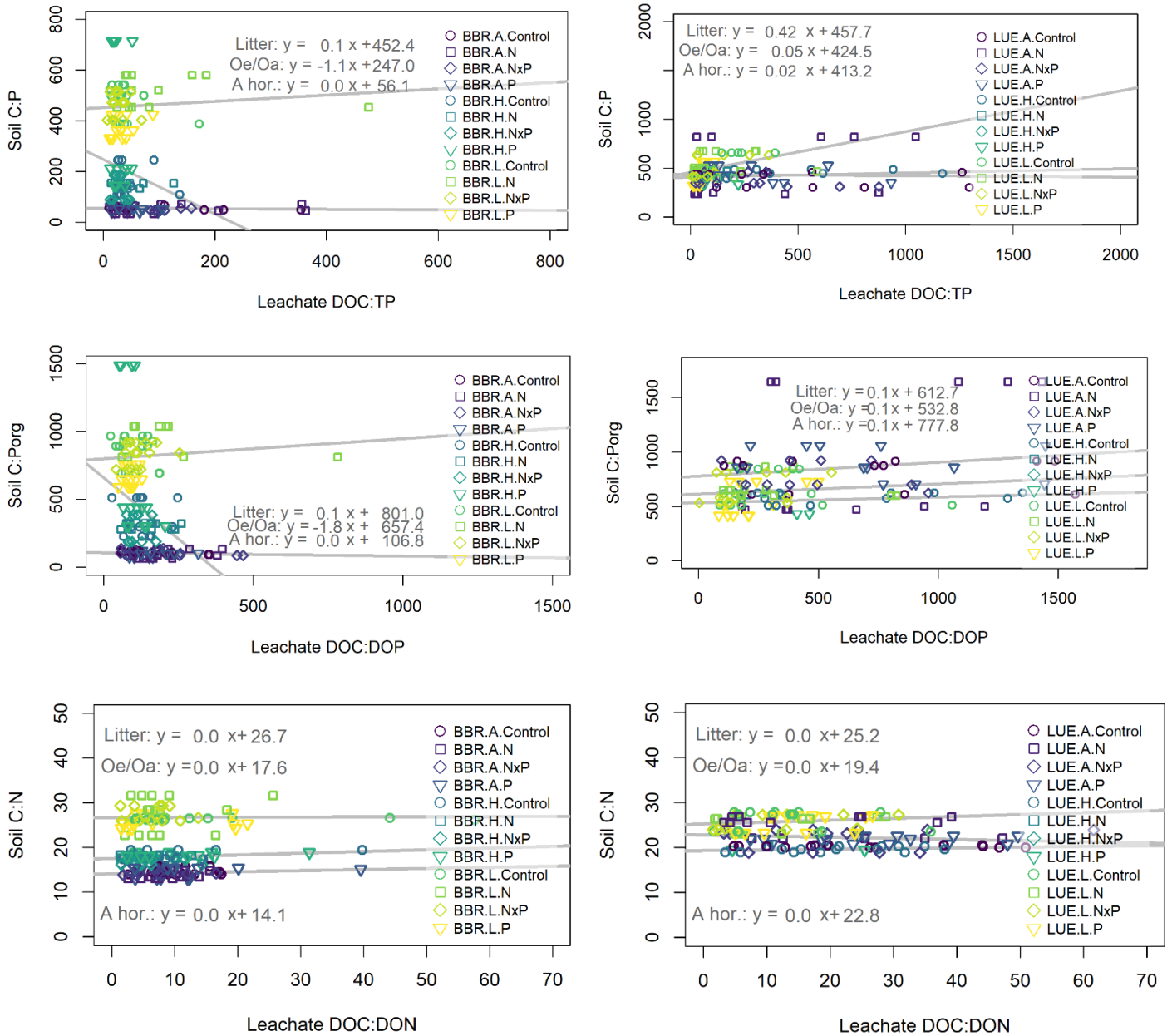


Figure S4: Relation of the dissolved organic carbon to total dissolved phosphorus (DOC:TDP) ratio versus soil carbon to total phosphorus (C:P<sub>tot</sub>) ratio as well as leachate dissolved organic carbon to dissolved organic nitrogen (DOC:DON) to soil C:N

Relation of leachate DOC:DTP and soil C:P<sub>tot</sub> (soil was sampled in July 2019) as affected by horizons (litter, Oe/Oa, and A horizon) and fertilization (N addition, P addition, N and P addition, and control) at the two sites BBR (High-P site) and LUE (Low-P site).

No relation between soil nutrient stoichiometry and leachate nutrient stoichiometry – in accordance with the laboratory experiment by Brödlin et al. (2019) for the high-P site BBR.

## SI 10: Fluxes to deposition, stock to fertilization

Table S11: Literature on nitrogen (N) and phosphorus (P) atmospheric deposition

Source	Atm. P deposition g P m <sup>-2</sup> yr <sup>-2</sup>	Source	Atm. N deposition g N m <sup>-2</sup> yr <sup>-1</sup>
Newman 1995*	0.007	BBR (Brumme et al., 2021)	<b>2.1</b>
Newman 1995* (Tipping et al., 2014)	0.012	LUE (NW-FVA, 2020)	<b>1.0</b>
(Qualls and Haines, 1991)	0.033		
Möller unpubl. *	0.030		
(Sohrt et al., 2019)	0.010		
	0.06		
<b>MEAN</b>	<b>0.03</b>		

\*from (Bol et al., 2016)

Table S12: Nitrogen (N) and phosphorus (P) annual fluxes compared to atmospheric N and P deposition.

Site	Horizon	Annual total P fluxes from control plots			Leaching as compared to deposition			Annual total N fluxes from control plots		Leaching as compared to deposition
		g P m <sup>-2</sup> y <sup>-1</sup>			%			g N m <sup>-2</sup> yr <sup>-1</sup>		%
		min	max	mean	min	max	mean	BBR	LUE	
BBR	Litter	0.05			714%	83%	<b>197%</b>	0.449		<b>22%</b>
BBR	Oe/Oa	0.06			857%	100%	<b>237%</b>	0.734		<b>36%</b>
BBR	A	0.039			557%	65%	<b>154%</b>	0.625		<b>30%</b>
LUE	Litter	0.043			614%	72%	<b>170%</b>	0.717		<b>68%</b>
LUE	Oe/Oa	0.028			400%	47%	<b>111%</b>	0.653		<b>62%</b>
LUE	A	0.012			171%	20%	<b>47%</b>	0.292		<b>28%</b>
<b>Deposition literature</b>		min	max	<b>mean</b>				<b>BBR</b>	<b>LUE</b>	
		0.01	0.06	<b>0.03</b>				<b>2.05</b>	<b>1.0</b>	



Table S13: Change in nitrogen (N) and phosphorus (P) leaching due to fertilization at the high-P site (BBR; Bad Brückenau) and the low-P site (LUE, Unterlüss) in the litter and the Oe/Oa horizon.

<b>Site: horizon</b>	<b>Change of total P leaching due to P fertilization</b>	<b>Change of total P leaching due to N fertilization</b>	<b>Change of total P leaching due to NxP fertilization</b>	<b>Change of total P leaching due to NxP fertilization</b>
	compared to control	compared to control	compared to control	compared to N addition
	% to control	% to control	% to control	% to N addition
<b>High-P: Litter</b>	9	0.6	111	109
<b>High-P: Oe/Oa</b>	51	33	75	43
<b>Low-P: Litter</b>	31	-11	-28	-16
<b>Low-P: Oe/Oa</b>	156	198	10	-188

<b>Site: horizon</b>	<b>Change of total N leaching due to N fertilization</b>	<b>Change of total N leaching due to P fertilization</b>	<b>Change of total N leaching due to NxP fertilization</b>	<b>Change of total N leaching due to NxP fertilization</b>
	compared to control	compared to control	compared to control	compared to P addition
	% to control	% to control	% to control	% to P addition
<b>High-P: Litter</b>	129	19	157	137
<b>High-P: Oe/Oa</b>	118	18	85	67
<b>Low-P: Litter</b>	53	-47	-31	17
<b>Low-P: Oe/Oa</b>	114	8	30	21

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