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Supplementary Material

Spatiotemporal variation of aluminium and micro- and macronutrients in the soil solution of a coniferous forest after low-intensity prescribed surface fires

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Table S1. Cumulative fluxes (kg ha^{-1}) of Al and nutrients (Ca, Fe, K, Mg, Mn, Na, P, S) in the organic layer, A and B horizon of the control (CT) and fire-manipulated (FM) plot; and fixed and model characteristics for linear mixed models predicting fluxes (kg ha^{-1}) of nutrients for pre-fire phase (Oct 2012 – June 2013)

The model parameters were based on log-transformed data and were transformed back for further interpretation. Fixed effects were: "Fire" for comparison between CT and FM plots before the fire manipulation. Random effects were site, location, and lysimeter ID in a nested design. Model characteristics were described by R^2m (marginal R^2), R^2c (conditional R^2), AIC (Akaike Information Criterion), and *n* (number of observations). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. b.d.l. – below detection limit (ICP-OES analysis)

Pre-fire	Cumulative fluxes (kg ha^{-1})		Linear mixed model						
			Fixed effects			Model characteristics			
	CT	FM (pre)	Intercept		Fire	R^2m (%)	R^2c (%)	AIC	n
Organic layer									
Al	1.81 ± 0.72	1.02 ± 0.33	0.16 ± 1.35	***	0.28 ± 1.55	4.3	39.6	319	97
Ca	9.11 ± 3.00	10.48 ± 5.63	0.82 ± 1.49		1.06 ± 1.59	0.8	46.2	323	97
Fe	1.49 ± 0.75	0.73 ± 0.24	0.11 ± 1.50	***	0.17 ± 1.64	2.0	48.8	322	97
K	11.46 ± 3.28	7.42 ± 2.55	1.11 ± 1.39		1.90 ± 1.61	3.8	48.8	316	97
Mg	3.37 ± 1.46	4.17 ± 3.19	0.20 ± 1.79	**	0.31 ± 1.62	2.0	59.9	324	97
Mn	0.26 ± 0.10	0.22 ± 0.09	0.02 ± 1.44	***	0.03 ± 1.64	1.7	49.6	322	97
Na	1.36 ± 0.41	0.93 ± 0.34	0.15 ± 1.33	***	0.24 ± 1.44	4.4	35.5	304	97
P	0.68 ± 0.33	0.75 ± 0.40	0.05 ± 1.48	***	0.03 ± 1.76	1.1	42.8	240	69
S	4.58 ± 1.37	2.93 ± 1.00	0.48 ± 1.31	**	0.81 ± 1.47	4.7	36.0	308	97

A horizon									
Al	2.68 ± 0.95	2.75 ± 1.12	0.22 ± 1.43	***	0.22 ± 1.66	0.002	45.5	402	116
Ca	7.13 ± 2.62	5.46 ± 2.62	0.56 ± 1.54		0.66 ± 1.60	0.3	38.1	409	116
Fe	2.42 ± 1.35	2.43 ± 1.10	0.15 ± 1.48	***	0.12 ± 1.74	0.5	50.4	404	116
K	7.20 ± 1.96	7.70 ± 2.65	0.66 ± 1.40		0.68 ± 1.60	0.01	41.3	394	116
Mg	2.61 ± 1.22	1.76 ± 1.04	0.15 ± 2.02	**	0.18 ± 1.58	0.4	59.0	403	116
Mn	0.79 ± 0.74	0.30 ± 0.16	0.02 ± 1.86	***	0.01 ± 1.97	0.03	58.6	455	116
Na	0.99 ± 0.33	1.01 ± 0.35	0.08 ± 1.34	***	0.08 ± 1.52	0.1	34.8	384	116
P	0.39 ± 0.21	0.48 ± 0.41	0.03 ± 1.57	***	0.03 ± 1.88	0.2	51.9	250	75
S	3.73 ± 1.23	4.07 ± 1.46	0.29 ± 1.41	***	0.24 ± 1.62	0.4	41.0	396	116
B horizon									
Al	2.07 ± 1.89	3.36 ± 2.24	0.11 ± 1.80	***	0.05 ± 2.16	5.6	5.6	170	49
Ca	4.72 ± 2.70	5.47 ± 3.24	0.27 ± 1.81	*	0.20 ± 2.02	0.9	6.9	160	49
Fe	1.24 ± 1.18	3.53 ± 2.49	0.06 ± 1.94	***	0.02 ± 2.39	10.6	10.6	171	49
K	5.17 ± 2.59	3.53 ± 2.35	0.25 ± 1.76	*	0.20 ± 1.96	0.4	5.8	162	49
Mg	1.04 ± 0.88	0.84 ± 0.49	0.05 ± 1.55	***	0.03 ± 1.77	3.2	3.2	153	49
Mn	2.03 ± 1.71	1.12 ± 0.63	0.01 ± 3.78	***	0.002 ± 2.67	5.3	51.5	173	49
Na	1.52 ± 1.30	1.01 ± 0.94	0.05 ± 1.95	***	0.04 ± 2.20	0.7	7.5	166	49
P	*b.d.l.*	*b.d.l.*	-		-	-	-	-	-

S	4.01 ± 3.11	3.50 ± 2.31	0.16 ± 1.73	**	0.09 ± 2.04		3.5	3.5	164.7	49

Table S2. Cumulative fluxes (kg ha^{-1}) of Al and nutrients (Ca, Fe, K, Mg, Mn, Na, P, S) in the organic layer, A and B horizon of the control (CT) and fire-manipulated (FM) plot; and fixed and model characteristics for linear mixed models predicting fluxes (kg ha^{-1}) of nutrients for post-fire phase I (June 2013 – Apr 2014)

The model parameters were based on log-transformed data and were transformed back for further interpretation. Fixed effects were: “Fire” for medium-term effects (>3 months after fire manipulation), “Time after fire” (square root of days after fire treatment), and “Soil temperature” (at 5 cm depth below the soil surface). Random effects were site, location, and lysimeter ID in a nested design. Model characteristics were described by R^2m (marginal R^2), R^2c (conditional R^2), AIC (Akaike Information Criterion), and *n* (number of observations). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Post-fire I	Cumulative fluxes (kg ha^{-1})		Linear mixed model							
			Fixed effects				Model characteristics			
	CT	FM (post)	Intercept	Fire “medium-term”	Time after fire	Soil temperature	R^2m (%)	R^2c (%)	AIC	n
Organic layer										
Al	7.03 ± 3.11	1.19 ± 0.97	0.24 ± 2.18	0.07 ± 2.59	0.01 ± 12.19	-	11.6	50.2	226	58
Ca	15.12 ± 10.54	6.03 ± 4.55	0.80 ± 1.75	0.41 ± 1.75	0.28 ± 12.74	-	5.6	12.9	200	58
Fe	6.54 ± 2.92	1.17 ± 0.91	0.19 ± 2.29	0.05 ± 2.76	0.02 ± 13.42	-	10.7	52.2	226	58

K	15.74 ± 4.72	7.65 ± 5.18	1.33 ± 1.68		0.52 ± 1.64	0.13 ± 12.49		-	10.8	16.7	211	58
Mg	3.76 ± 2.92	0.90 ± 0.68	0.18 ± 1.81	**	0.07 ± 1.73	0.08 ± 11.51		-	9.7	21.9	196	58
Mn	2.65 ± 1.21	0.27 ± 0.37	0.08 ± 2.33	**	0.03 ± 1.66	0.002 ± 16.03		-	8.1	33.7	217	58
Na	4.29 ± 1.63	2.11 ± 1.31	0.55 ± 1.52		0.34 ± 1.47	0.0004 ± 8.20	**	-	22.1	22.1	182	58
P	1.09 ± 1.02	1.60 ± 1.44	0.17 ± 1.93	**	0.17 ± 1.81	0.0001 ± 32.24	*	-	10.7	13.7	168	46
S	9.05 ± 3.82	6.11 ± 4.53	0.89 ± 1.64		0.50 ± 1.59	0.01 ± 11.01		-	9.5	11.2	195	58
A horizon												
Al	2.80 ± 1.02	2.44 ± 1.42	0.08 ± 1.50	***	0.04 ± 1.66	0.71 ± 5.28		-	5.7	28.8	502	134
Ca	11.33 ± 5.23	5.79 ± 3.11	0.36 ± 1.44	**	0.19 ± 1.52	3.09 ± 3.91		-	7.2	33.1	426	134
Fe	3.95 ± 2.27	3.49 ± 2.67	0.08 ± 1.58	***	0.04 ± 1.82	0.56 ± 5.37		-	3.2	34.0	518	134
K	9.52 ± 3.08	9.81 ± 4.84	0.31 ± 1.46	**	0.25 ± 1.60	2.19 ± 4.59		-	1.5	26.5	475	134
Mg	2.43 ± 1.19	1.57 ± 0.97	0.07 ± 1.61	***	0.05 ± 1.48	0.70 ± 3.92		-	3.4	35.0	432	134
Mn	1.46 ± 0.79	0.68 ± 0.53	0.04 ± 2.17	***	0.02 ± 1.67	0.01 ± 4.32		-	1.4	48.7	493	134
Na	2.71 ± 0.83	2.48 ± 1.05	0.25 ± 1.32	***	0.21 ± 1.41	0.001 ± 3.11	***	-	13.4	34.7	390	134

P	0.56 ± 0.34	0.85 ± 0.66	0.02 ± 1.55	***	0.03 ± 1.69	0.01 ± 6.50		-		0.6	26.0	371	104
S	4.95 ± 1.66	4.86 ± 2.66	0.22 ± 1.38	***	0.17 ± 1.49	0.22 ± 3.94		-		1.2	23.5	433	134
B horizon													
Al	2.82 ± 1.85	3.51 ± 2.10	0.10 ± 1.76	***	0.11 ± 1.50	0.36 ± 6.25		-		0.5	49.3	234	69
Ca	5.54 ± 3.88	6.92 ± 3.90	0.37 ± 1.50	*	0.38 ± 1.50	0.21 ± 3.90		-		0.2	42.8	190	69
Fe	2.05 ± 1.82	2.95 ± 1.75	0.03 ± 1.84	***	0.07 ± 1.65	1.59 ± 5.43	*	-		9.2	59.6	234	69
K	7.25 ± 6.91	7.62 ± 5.17	0.33 ± 1.79		0.32 ± 2.10	0.08 ± 5.39		-		0.5	55.1	221	69
Mg	0.94 ± 0.52	1.68 ± 1.17	0.06 ± 1.55	***	0.07 ± 1.67	0.03 ± 5.11		-		0.8	35.5	211	69
Mn	1.56 ± 0.81	3.38 ± 2.15	0.05 ± 1.75	***	0.11 ± 1.62	-		0.03 ± 1.20	***	16.2	50.7	248	69
Na	2.14 ± 0.95	2.83 ± 2.16	0.20 ± 1.72	**	0.28 ± 1.53	0.0003 ± 4.76	***	-		14.4	51.8	211	69
P	0.15 ± 0.01	0.16 ± 0.01	0.03 ± 2.66	**	0.01 ± 2.74	0.002 ± 11.01		-		2.6	81.9	76	21
S	3.69 ± 2.22	4.39 ± 2.54	0.16 ± 1.69	***	0.21 ± 1.77	0.08 ± 4.83		-		1.4	47.6	207	69

Table S3. Spearman correlation coefficient R_s and significance for the relationship between concentrations of Ca and Mg, K and N, Al and Fe, and DOC and DN divided into the three depth layers (organic layer, A and B horizon), three phases (pre-fire, post-fire I, post-fire II), and treatment (control CT and fire-manipulation FM)

$^{n.s.}$ not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

	pre-fire		post-fire I		post-fire II	
	CT	FM (pre)	CT	FM (post)	CT	FM (post)
organic layer						
Ca with Mg	0.98***	0.73***	0.96***	0.67***	0.87***	0.89***
K with Na	0.65***	0.67***	-0.14$^{n.s.}$	0.05$^{n.s.}$	0.46***	0.59***
Al with Fe	0.79***	0.88***	0.98***	0.89***	0.92***	0.88***
DOC with DN	0.51***	0.75***	0.41*	0.82***	0.16$^{n.s.}$	0.17$^{n.s.}$
A horizon						
Ca with Mg	0.82***	0.89***	0.80***	0.91***	0.87***	0.88***
K with Na	0.48***	0.68***	-0.04$^{n.s.}$	-0.01$^{n.s.}$	0.61***	0.32***
Al with Fe	0.88***	0.74***	0.86***	0.89***	0.78***	0.84***
DOC with DN	0.68***	0.75***	0.33**	0.33**	0.69***	0.35***
B horizon						
Ca with Mg	0.73***	0.01$^{n.s.}$	0.76***	0.48**	0.80***	0.92***
K with Na	-0.48*	0.32$^{n.s.}$	-0.33$^{n.s.}$	0.09$^{n.s.}$	-0.07$^{n.s.}$	-0.27*
Al with Fe	0.63***	0.78***	0.34$^{n.s.}$	0.53***	0.18$^{n.s.}$	0.41***
DOC with DN	0.67**	0.62***	-0.35$^{n.s.}$	0.16$^{n.s.}$	-0.67***	-0.63***

Table S4. Summary of annual nutrient uptake, semiannual element concentration in needles, and nutrient fluxes via litterfall in a *Pinus sylvestris* stand

	Pinus sylvestris		
Element	annual nutrient uptake (yield class I) [A] (kg ha^{-1})	element concentration in needles (semiannual) [B] (% dry mass)	nutrient fluxes in litterfall (return fluxes) [C] (kg ha^{-1})
Al	-	0.03 - 0.06	-
Ca	20.5	0.15 - 0.50	5.2 - 13.5
Fe	-	0.004 – 0.06	0.1 - 0.5
K	14.2	0.35 - 0.50	1.2 - 4.4
Mg	3.7	0.05 - 0.15	0.6 - 1.6
Mn	-	0.01 - 0.10	0.7 - 2.7
P	3.9	0.10 - 0.30	0.7 - 1.9

[A] Ehwald (1957)

[B] Lyr *et al.* (1992) and references therein

[C] Ukonmaanaho *et al.* (2008)

Table S5. Short-term cumulative fluxes (kg ha^{-1}) of Al and nutrients (Ca, Fe, K, Mg, Mn, Na, P, S) in the organic layer, A and B horizon of the control (CT) and fire-manipulated (FM) plot for post-fire I (June 2013 – Apr 2014) and post-fire II (Apr 2014 – Dec 2014)

	Cumulative fluxes – Post-fire I „short-term“ (kg ha^{-1})		Cumulative fluxes – Post-fire II “short-term” (kg ha^{-1})	
	CT	FM	CT	FM
Organic layer				
Al	4.48 ± 2.21	0.22 ± 0.57	1.12 ± 0.35	1.10 ± 0.53
Ca	5.39 ± 1.78	2.38 ± 3.78	12.97 ± 6.95	23.34 ± 14.49
Fe	3.99 ± 1.99	0.18 ± 0.34	0.67 ± 0.45	0.77 ± 0.53
K	6.06 ± 2.66	2.15 ± 2.93	11.32 ± 2.59	11.12 ± 2.84
Mg	1.14 ± 0.53	0.41 ± 0.59	4.14 ± 4.04	6.23 ± 4.33
Mn	1.73 ± 0.29	0.14 ± 0.36	0.96 ± 0.40	1.06 ± 0.57
Na	1.19 ± 0.25	0.44 ± 0.56	3.60 ± 1.26	3.08 ± 0.62
P	0.34 ± 0.69	0.24 ± 0.40	1.73 ± 0.78	3.85 ± 1.37
S	2.96 ± 1.52	1.57 ± 2.53	4.77 ± 2.04	5.64 ± 1.45
A horizon				
Al	1.02 ± 0.65	1.29 ± 1.19	2.35 ± 0.66	1.73 ± 0.56
Ca	2.95 ± 1.11	2.74 ± 1.99	7.59 ± 1.97	14.60 ± 3.70
Fe	1.36 ± 1.41	1.23 ± 0.97	2.43 ± 0.91	1.60 ± 0.69
K	3.59 ± 1.65	3.51 ± 1.99	8.59 ± 1.87	12.06 ± 3.09
Mg	0.66 ± 0.27	0.65 ± 0.51	2.03 ± 0.64	4.88 ± 1.52
Mn	0.38 ± 0.33	0.20 ± 0.25	0.81 ± 0.31	1.66 ± 0.74
Na	0.81 ± 0.55	0.74 ± 0.55	3.35 ± 0.60	3.26 ± 0.66
P	0.29 ± 0.26	0.26 ± 0.34	0.82 ± 0.38	1.69 ± 0.52
S	1.95 ± 1.16	2.08 ± 2.15	4.59 ± 0.96	6.49 ± 1.55
B horizon				
Al	1.01 ± 1.73	1.39 ± 1.65	3.76 ± 2.31	5.77 ± 5.04

Ca	1.83 ± 3.75	2.53 ± 1.71	8.49 ± 3.72	53.31 ± 48.20
Fe	1.07 ± 1.80	1.14 ± 1.16	0.69 ± 0.52	1.80 ± 1.67
K	2.58 ± 6.67	2.29 ± 2.05	11.34 ± 6.14	20.39 ± 10.46
Mg	0.33 ± 0.46	0.47 ± 0.67	1.76 ± 0.95	10.29 ± 6.31
Mn	0.42 ± 0.47	0.53 ± 0.72	2.05 ± 1.49	11.43 ± 9.76
Na	0.49 ± 0.77	0.53 ± 0.39	2.45 ± 1.20	3.36 ± 1.33
P	0.06 ± -	0.08 ± -	0.68 ± 1.25	0.86 ± 0.89
S	1.25 ± 2.10	1.27 ± 1.11	2.85 ± 1.44	5.07 ± 1.58

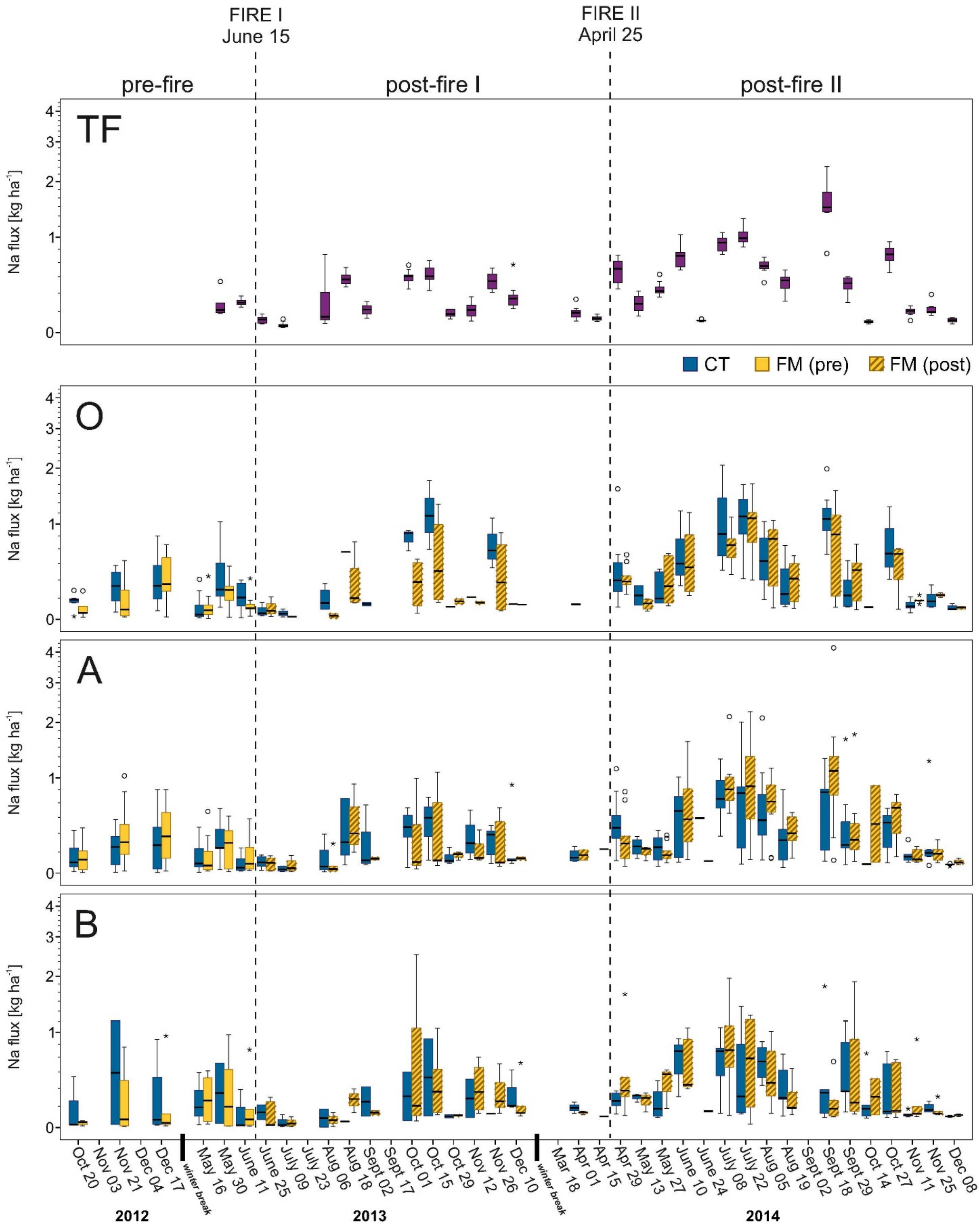

Fig. S1. Fluxes (kg ha^{-1}, log-scale) of sodium (Na) in throughfall (TF) and leachates from organic layer (O), A and B horizon from unburned (CT) and fire-affected (FM) lysimeters during the pre-fire phase and two post-fire phases (I and II). Fire events FIRE I and FIRE II are indicated by a dashed line. The winter breaks were from Dec 2012 to May 2013, and from Dec 2013 to Mar 2014. Sampling dates with no boxplots indicate sampling volumes < 30 cm^3 or no sampling. Boxplots contain median, box: 25, 75% percentile, whisker – min max without outliers and extremes, circle – outlier 1.5 to 3 times < or > box, asterisks – extreme > 3 times of box.

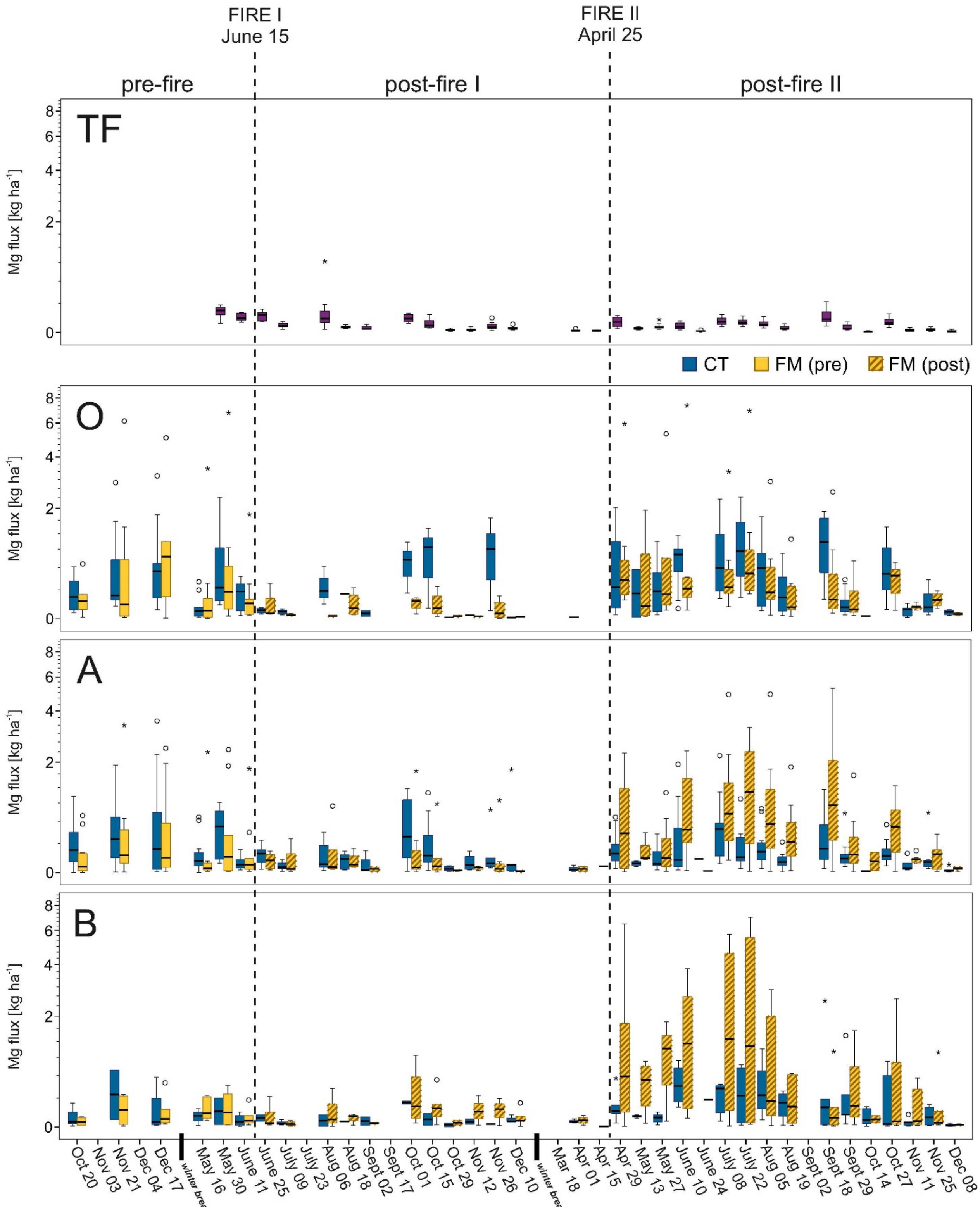

Fig. S2. Fluxes (kg ha^{-1}, log-scale) of magnesium (Mg) in throughfall (TF) and leachates from organic layer (O), A and B horizon from unburned (CT) and fire-affected (FM) lysimeters during the pre-fire phase and two post-fire phases (I and II). Fire events FIRE I and FIRE II are indicated by a dashed line. The winter breaks were from Dec 2012 and May 2013, and from Dec 2013 to Mar 2014. Sampling dates with no boxplots indicate sampling volumes < 30 cm^3 or no sampling. Boxplots contain median, box: 25, 75% percentile, whisker – min max without outliers and extremes, circle – outlier 1.5 to 3 times < or > box, asterisks – extreme > 3 times of box.

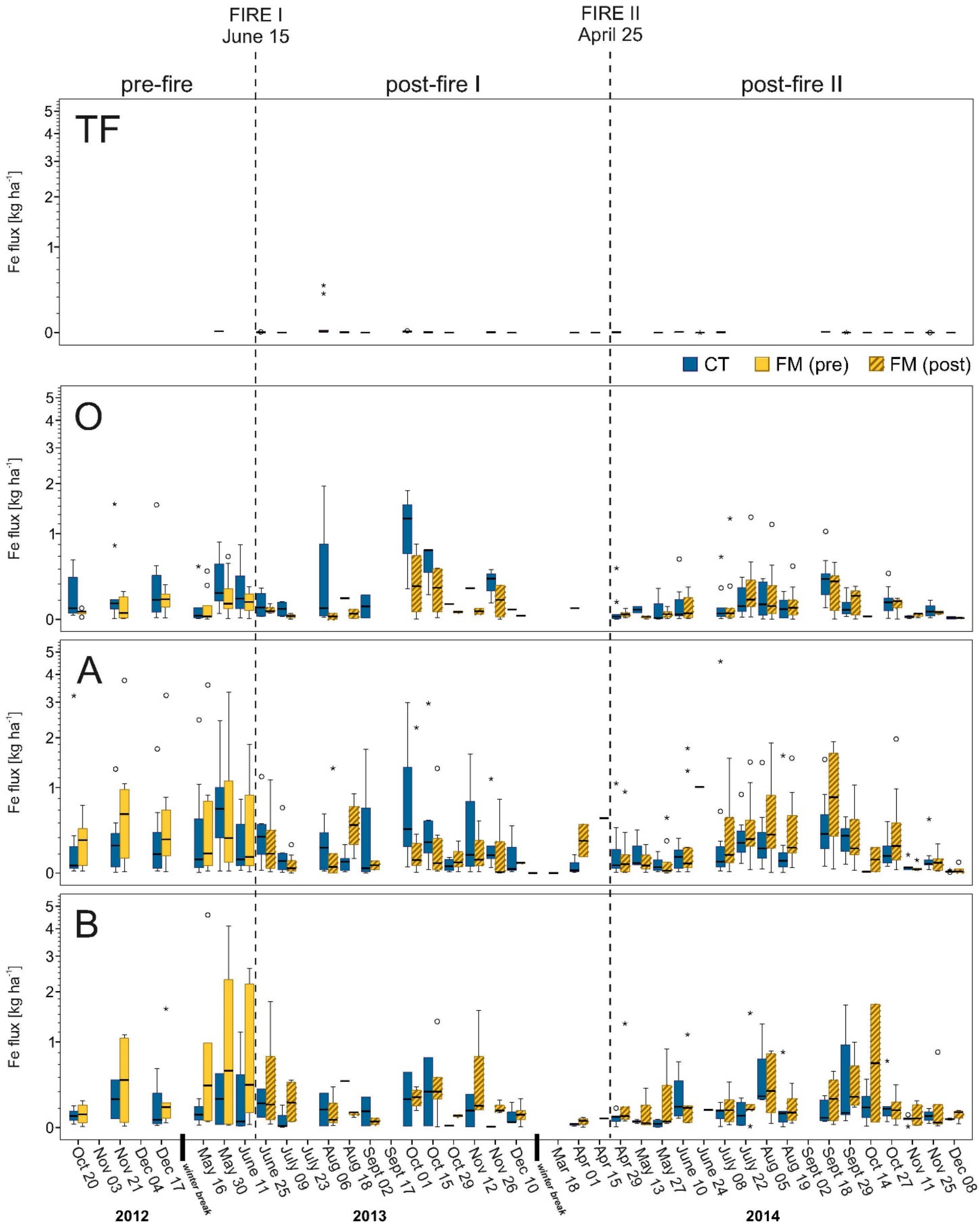

Fig. S3. Fluxes (kg ha^{-1}, log-scale) of iron (Fe) in throughfall (TF) and leachates from organic layer (O), A and B horizon from unburned (CT) and fire-affected (FM) lysimeters during the pre-fire phase and two post-fire phases (I and II). Fire events FIRE I and FIRE II are indicated by a dashed line. The winter breaks were from Dec 2012 and May 2013, and from Dec 2013 to Mar 2014. Sampling dates with no boxplots indicate sampling volumes < 30 cm^3 or no sampling. Boxplots contain median, box: 25, 75% percentile, whisker – min max without outliers and extremes, circle – outlier 1.5 to 3 times < or > box, asterisks – extreme > 3 times of box.