Gypsum amendment influences soil and plant chemical composition temporarily

Markku Yli-Halla[1], Antti Taskinen[2] and Petri Ekholm[2]

[1]*University of Helsinki, Department of Agricultural Sciences, Viikinkaari 9, FI-00790 Helsinki, Finland*

[2]*Finnish Environment Institute, Latokartanonkaari 11, FI-00790 Helsinki, Finland*

e-mail: petri.ekholm@syke.fi

Supplementary material

Table S1. Runoff and frost duration in the three periods after the gypsum spreading corresponding to soil sampling events. Frost duration is estimated for open areas by the WSFS system of SYKE (Vehviläinen et al. 2001).

Period	Length	Runoff (mm)		Frost duration (d)
	Months	Per period	Cumulative	
From the end of gypsum spreading to the 2. soil sampling (Nov. 2016–May 2017)	6	73	73	168
From the 2. to the 3. soil sampling (May 2017–May 2018)	12	342	415	117
From the 3. to the 4. soil sampling (May 2018–April 2020)	23	695	1110	210

Table S2. Precipitation and temperature sum (>5°C) in the time interval from the estimated start of the growing season till the sampling of plants (20 April–1 July) in four years: before the gypsum spreading (2016) and in one, two and four years after the gypsum spreading (2017, 2018 and 2020, respectively).

Year	Precipitation (mm)	Temperature sum (°C)
2016	129	563
2017	134	399
2018	75	625
2020	83	542

Table S3 (1/2). Results of the mixed-effects model for soil chemistry. Log transformed variables (except pH) were used. "Gypsum = Yes" refers to the amended plots (as opposed to unamended plots) and "Clay = Yes" refers to the plots with clay soils (as opposed to coarser mineral soils). Estimate refers to the effect size, which in case of Intercept consists of comparison level of factors, i.e. when "Gypsum = No", "Clay = No", "Year = 2016". Other estimates represent the difference to this level. The covariates, Loss on ignition (LOI) and pH were standardized (mean 0, standard deviation 1). Significances $p < 0.05$ given in **bold,** ns. refers to cases where the covariate or the interaction of the fixed effects is not significant.

Fixed effect			**Sulfur**					**Electrical conductivity**		
	Estimate	SE	DF	t-value	p-value	Estimate	SE	DF	t-value	p-value
Intercept	1.88	0.0787	160	23.9	**<0.001**	-0.475	0.0733	160	-6.48	**<0.001**
Standardized(LOI)	0.0635	0.0381	160	1.67	0.098	0.124	0.0367	160	3.38	**<0.001**
Standardized(pH)	-0.0901	0.0396	160	-2.27	**0.024**	0.173	0.0348	160	4.98	**<0.001**
Gypsum = Yes	0.171	0.0978	53	1.75	0.087	0.224	0.0849	53	2.63	**0.011**
Clay = Yes	0.146	0.0880	53	1.65	0.104	0.135	0.0898	53	1.50	0.139
Year = 2017	0.596	0.116	160	5.12	**<0.001**	0.495	0.0707	160	7.01	**<0.001**
Year = 2018	0.0617	0.0927	160	0.666	0.507	0.201	0.0472	160	4.26	**<0.001**
Year = 2020	-0.0603	0.0948	160	-0.635	0.526	0.385	0.0596	160	6.46	**<0.001**
Gypsum = Yes & Year = 2017	1.83	0.187	160	9.84	**<0.001**	0.849	0.114	160	7.47	**<0.001**
Gypsum = Yes & Year = 2018	0.761	0.148	160	5.14	**<0.001**	0.224	0.0757	160	2.96	**0.004**
Gypsum = Yes & Year = 2020	0.0280	0.151	160	0.185	0.854	-0.0198	0.0950	160	-0.208	0.835
			Potassium					**Phosphorus**		
Intercept	5.23	0.0794	160	65.8	**<0.001**	2.42	0.167	160	14.5	**<0.001**
Standardized(LOI)	0.115	0.0264	160	4.36	**<0.001**	0.116	0.0471	160	2.47	**0.010**
Standardized(pH)	-0.0302	0.0214	160	-1.41	0.160	0.193	0.0355	160	5.42	**<0.001**
Gypsum = Yes	0.0780	0.0734	sss	1.06	0.293	0.193	0.159	53	1.21	0.231
Clay = Yes	0.0638	0.0972	53	0.657	0.514	-0.0562	0.203	53	-0.277	0.783
Year = 2017	0.0452	0.0458	160	0.988	0.325	0.110	0.0704	160	1.56	0.122
Year = 2018	-0.160	0.0504	160	-3.18	**0.002**	-0.0758	0.0538	160	-1.41	0.161
Year = 2020	-0.0623	0.0466	160	-1.34	0.183	-0.135	0.0693	160	-1.95	0.053
Clay = Yes & Year = 2017	0.0828	0.0556	160	1.49	0.138	-0.0397	0.0852	160	-0.466	0.642
Clay = Yes & Year = 2018	0.158	0.0623	160	2.53	**0.012**	0.151	0.0668	160	2.26	**0.025**
Clay = Yes & Year = 2020	0.115	0.0576	160	2.00	**0.047**	0.133	0.0856	160	1.55	0.123

Table S3 continues (2/2).

Fixed effect	**Calcium**					**Magnesium**				
	Estimate	SE	DF	t-value	p-value	Estimate	SE	DF	t-value	p-value
Intercept	7.68	0.0300	163	257	**<0.001**	5.43	0.0884	163	61.5	**<0.001**
Standardized(LOI)	0.173	0.0151	163	11.5	**<0.001**	0.104	0.0324	163	3.21	**0.002**
Standardized(pH)	0.302	0.0147	163	20.6	**<0.001**	0.00397	0.0250	163	0.159	0.874
Gypsum = Yes	0.0943	0.0322	53	2.93	**0.005**	-0.334	0.101	53	-3.32	**0.002**
Clay = Yes	0.127	0.0359	53	3.54	**<0.001**	0.672	0.106	53	6.33	**<0.001**
Year = 2017	0.228	0.0212	163	10.8	**<0.001**	0.0909	0.0257	163	3.54	**<0.001**
Year = 2018	-0.0556	0.0188	163	-2.96	**0.004**	-0.122	0.0249	163	-4.89	**<0.001**
Year = 2020	0.0499	0.0289	163	1.73	0.086	-0.0216	0.0246	163	-0.879	0.381
Gypsum = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
	pH					**Loss on ignition**				
Intercept	6.20	0.111	164	55.9	**<0.001**	1.81	0.0555	161	32.6	0.381
Standardized(LOI)	0.0147	0.0422	164	0.348	0.728	ns.	ns.	ns.	ns.	ns.
Standardized(pH)	ns.	ns.	ns.	ns.	ns.	0.00543	0.0123	161	0.443	0.659
Gypsum = Yes	0.00495	0.124	53	0.0398	0.968	-0.0857	0.0623	53	-1.38	0.174
Clay = Yes	0.393	0.129	53	3.04	**0.004**	0.142	0.0669	53	2.12	**0.039**
Year = 2017	-0.148	0.0414	164	-3.59	**<0.001**	-0.0688	0.0192	161	-3.58	**<0.001**
Year = 2018	-0.0374	0.0339	164	-1.10	0.271	0.0149	0.0201	161	0.737	0.462
Year = 2020	-0.0465	0.0397	164	-1.17	0.243	0.0134	0.0203	161	0.661	0.510
Clay = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	0.0638	0.0233	161	2.73	**0.007**
Clay = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	0.0184	0.0249	161	0.739	0.461
Clay = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	-0.0204	0.0251	161	-0.812	0.418

Table S4 (1/3). Results of the mixed-effects model for plant chemistry. Log transformed variables were used. “Gypsum = Yes” refers to the amended plots (as opposed to unamended plots) and “Clay = Yes” refers to the plots with clay soils (as opposed to coarser mineral soils). Estimate refers to the effect size, which in case of Intercept consists of comparison level of factors, i.e. when “Gypsum = No”, “Clay = No”, “Year = 2016”. Other estimates represent the difference to this level. Significances $p < 0.05$ given in **bold,** ns. refers to cases where the interaction of the fixed effects is not significant.

Fixed effect	**Sulfur**					**Calcium**				
	Estimate	SE	DF	t-value	p-value	Estimate	SE	DF	t-value	p-value
Intercept	0.713	0.128	148	5.58	**<0.001**	1.10	0.113	148	9.75	**<0.001**
Gypsum = Yes	0.114	0.136	148	0.834	0.406	0.399	0.115	148	3.47	**<0.001**
Clay = Yes	0.0597	0.145	148	0.412	0.681	0.271	0.138	148	1.97	0.050
Year = 2017	0.342	0.170	148	2.01	**0.047**	0.155	0.150	148	1.03	0.305
Year = 2018	0.467	0.187	32	2.50	**0.018**	0.252	0.150	34	1.68	0.102
Year = 2020	-0.212	0.149	32	-1.43	0.162	-0.130	0.150	34	-0.867	0.392
Gypsum = Yes & Clay = Yes	ns.	ns.	ns.	ns.	ns.	-0.403	0.136	148	-2.96	**0.004**
Gypsum = Yes & Year = 2017	0.565	0.182	148	3.11	**0.002**	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2018	0.485	0.200	32	2.43	**0.021**	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2020	0.0875	0.158	32	0.552	0.585	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2017	-0.209	0.193	148	-1.08	0.282	-0.0569	0.181	148	-0.314	0.754
Clay = Yes & Year = 2018	-0.583	0.212	32	-2.75	**0.001**	-0.368	0.181	34	-2.04	**0.049**
Clay = Yes & Year = 2020	-0.0743	0.169	32	-0.441	0.662	-0.148	0.181	34	-0.816	0.420
	Phosphorus					**Nitrogen**				
Intercept	1.16	0.0717	149	16.2	**<0.001**	3.15	0.0910	150	34.6	**<0.001**
Gypsum = Yes	0.0827	0.0429	149	1.93	0.056	0.0503	0.0651	150	0.774	0.440
Clay = Yes	0.107	0.0848	149	1.26	0.210	0.112	0.0692	150	1.62	0.107
Year = 2017	-0.126	0.0993	149	-1.27	0.206	0.163	0.0976	150	1.67	0.098
Year = 2018	0.0708	0.0980	34	0.722	0.475	0.0214	0.0883	36	0.243	0.809
Year = 2020	-0.112	0.0980	34	-1.14	0.261	-0.107	0.0911	36	-1.17	0.248
Gypsum = Yes & Clay = Yes	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2017	0.0602	0.120	149	0.503	0.616	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2018	-0.324	0.118	34	-2.74	**0.010**	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2020	-0.202	0.118	34	-1.71	0.097	ns.	ns.	ns.	ns.	ns.

Table S4 continues (2/3).

Fixed effect	Boron					Copper				
	Estimate	SE	DF	t-value	p-value	Estimate	SE	DF	t-value	p-value
Intercept	1.06	0.106	149	9.92	**<0.001**	1.70	0.129	148	13.1	**<0.001**
Gypsum = Yes	0.497	0.147	149	3.37	**<0.001**	-0.378	0.136	148	-2.78	**0.006**
Clay = Yes	0.307	0.108	149	2.85	**0.005**	-0.0698	0.158	148	-0.442	0.659
Year = 2017	0.0761	0.105	149	0.728	0.468	-0.211	0.171	148	-1.23	0.219
Year = 2018	0.486	0.104	36	4.68	**<0.001**	0.162	0.169	34	0.956	0.346
Year = 2020	0.459	0.104	36	4.42	**<0.001**	0.0439	0.169	34	0.259	0.797
Gypsum = Yes & Clay = Yes	-0.947	0.175	149	-5.39	**<0.001**	0.607	0.162	148	3.75	**<0.001**
Gypsum = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	0.177	0.207	148	0.859	0.392
Clay = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	-0.478	0.204	34	-2.34	**0.026**
Clay = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	-0.0843	0.204	34	-0.412	0.683
	Iron					**Selenium**				
Intercept	3.94	0.102	149	38.5	**<0.001**	-3.65	0.279	150	-13.1	**<0.001**
Gypsum = Yes	0.178	0.143	149	1.24	0.215	-0.457	0.224	150	-2.04	**0.043**
Clay = Yes	0.186	0.0688	149	2.70	**0.008**	0.258	0.238	150	1.08	0.281
Year = 2017	0.259	0.144	149	1.80	0.073	0.502	0.303	150	1.66	0.100
Year = 2018	-0.110	0.106	34	-1.04	0.307	0.657	0.303	36	2.17	**0.037**
Year = 2020	0.0665	0.122	34	0.543	0.591	-0.0958	0.303	36	-0.316	0.754
Gypsum = Yes & Clay = Yes	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2017	-0.230	0.223	149	-1.03	0.304	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2018	-0.0348	0.164	34	-0.213	0.833	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2020	-0.363	0.188	34	-1.93	0.062	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.

Table S4 continues (3/3).

Fixed effect	**Magnesium**					**Potassium**				
	Estimate	SE	DF	t-value	p-value	Estimate	SE	DF	t-value	p-value
Intercept	0.416	0.0573	150	7.25	**<0.001**	3.24	0.0726	150	44.7	**<0.001**
Gypsum = Yes	-0.0706	0.0406	150	-1.74	0.084	0.0547	0.0508	150	1.08	0.284
Clay = Yes	0.104	0.0432	150	2.40	**0.018**	0.0490	0.0540	150	0.906	0.366
Year = 2017	-0.0213	0.0666	150	-0.320	0.749	0.167	0.0762	150	2.20	**0.029**
Year = 2018	0.0196	0.0572	36	0.343	0.734	-0.165	0.0795	36	-2.07	**0.045**
Year = 2020	-0.115	0.0580	36	-1.98	0.055	-0.175	0.0697	36	-2.51	**0.016**
Gypsum = Yes & Clay = Yes	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2017	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2018	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2020	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.
	Zinc					**Manganese**				
Intercept	3.35	0.084	147	39.8	**<0.001**	3.65	0.120	150	30.6	**<0.001**
Gypsum = Yes	-0.611	0.122	147	-5.00	**<0.001**	-0.112	0.0991	150	-1.13	0.259
Clay = Yes	0.0404	0.100	147	0.402	0.688	-0.457	0.105	150	-4.34	**<0.001**
Year = 2017	-0.416	0.150	147	-2.77	**0.006**	0.298	0.127	150	2.35	**0.020**
Year = 2018	0.0860	0.136	32	0.631	0.533	0.327	0.125	36	2.62	**0.013**
Year = 2020	-0.224	0.141	32	-1.58	0.123	0.0224	0.125	36	0.180	0.858
Gypsum = Yes & Clay = Yes	0.715	0.125	147	5.73	**<0.001**	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2017	0.166	0.160	147	1.03	0.303	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2018	0.313	0.145	32	2.15	**0.039**	ns.	ns.	ns.	ns.	ns.
Gypsum = Yes & Year = 2020	-0.0977	0.151	32	-0.648	0.521	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2017	0.195	0.171	147	1.14	0.255	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2018	-0.351	0.155	32	-2.27	**0.030**	ns.	ns.	ns.	ns.	ns.
Clay = Yes & Year = 2020	-0.159	0.160	32	-0.995	0.327	ns.	ns.	ns.	ns.	ns.

Table S5. Concentrations of nitrogen, micronutrients and Se in plant material collected from fields amended with gypsum and from control fields. Ten fields amended with gypsum and 15 control fields were sampled. The results are expressed as mean values and the range. G = Gypsum.

Variable	G	June 2016	June 2017	July 2018	June 2020	Deficiency	Typical
N	No	26.1 (9.2–40.0)	31.1 (11.3–51.7)	26.8 (14.1–53.3)	23.6 (10.4–41.5)	<15–31[3]	12–18[4]
$g\ kg^{-1}$	Yes	30.8 (7.3–50.9)	33.3 (10.7–43.1)	28.8 (15.0–41.6)	24.3 (10.7–31.8)		
B[1]	No	4.5 (1.1–18)	4.8 (1.7–15.5)	6.3 (2.3–12.5)	6.1 (3.0–11.5)	<1.9–3.5[3]	5.6[5], 5.5–8.0[4]
$mg\ kg^{-1}$	Yes	3.2 (1.1–5.3)	3.2 (1.6–6.1)	7.6 (2.3–29.5)	5.3 (2.3–9.5)		
Cu	No	5.6 (2.7–9.6)	5.0 (2.7–10.4)	5.1 (2.6–8,7)	5.7 (2.6–9.8)	<2.3[3]	6.0[5], 2.8–6.2[6]
$mg\ kg^{-1}$	Yes	6.1 (2.6–10.0)	5.9 (2.7–9.4)	5.2 (2.6–9.1)	6.2 (2.6–18.5)		
Mn	No	41.1 (11.0–120)	52 (11.0–130)	61.5 (12.5–200)	42 (10.1–85.5)	<12.5[2]	76[5], 40–100[6]
$mg\ kg^{-1}$	Yes	27.9 (13.0–81.5)	38.7 (13.5–95.0)	52.1 (23–235)	27.7 (14.5–66.0)		
Fe	No	60.7 (22.0–111)	95.6 (25–320)	54.8 (35.5–122)	70.7 (36.5–250)	<34[3]	64[5], 48–82[6]
$mg\ kg^{-1}$	Yes	79.7 (21.5–150)	76.3 (31.5–102)	63.6 (48–92)	55.1 (30.0–81.0)		
Zn	No	29.5 (17.3–38.0)	24.8 (10.7–70.0)	27.9 (10.5–48.0)	22.2 (10.5–41.0)	<14[3]	24[5], 18–38[6]
$mg\ kg^{-1}$	Yes	30.0 (10.5–46.5)	27.5 (10.8–49.0)	33.2 (18.4–50)	19.5 (10.5–41.0)		
Se[1]	No	0.14 (0.01–0.89)	0.17 (0.01–1.23)	0.18 (0.01–1.03)	0.06 (0.01–0.36)		
$mg\ kg^{-1}$	Yes	0.02 (0.01–0.09)	0.07 (0.01–0.23)	0.17 (0.01–0.66)	0.09 (0.01–0.43)		

[1] Concentrations below the limit of determination were assumed to be 0.5 times the limit of determination. [2] Youngest mature leaf (Riechelman et al. 2021); [3] Barley at tillering (Reuter and Robinson 1997); [4] Timothy hay at harvesting stage (Jansson et al. 1985); [5] Spring wheat at heading (Sillanpää 1982); [6] Timothy hay at harvesting stage (Yläranta and Sillanpää 1984)

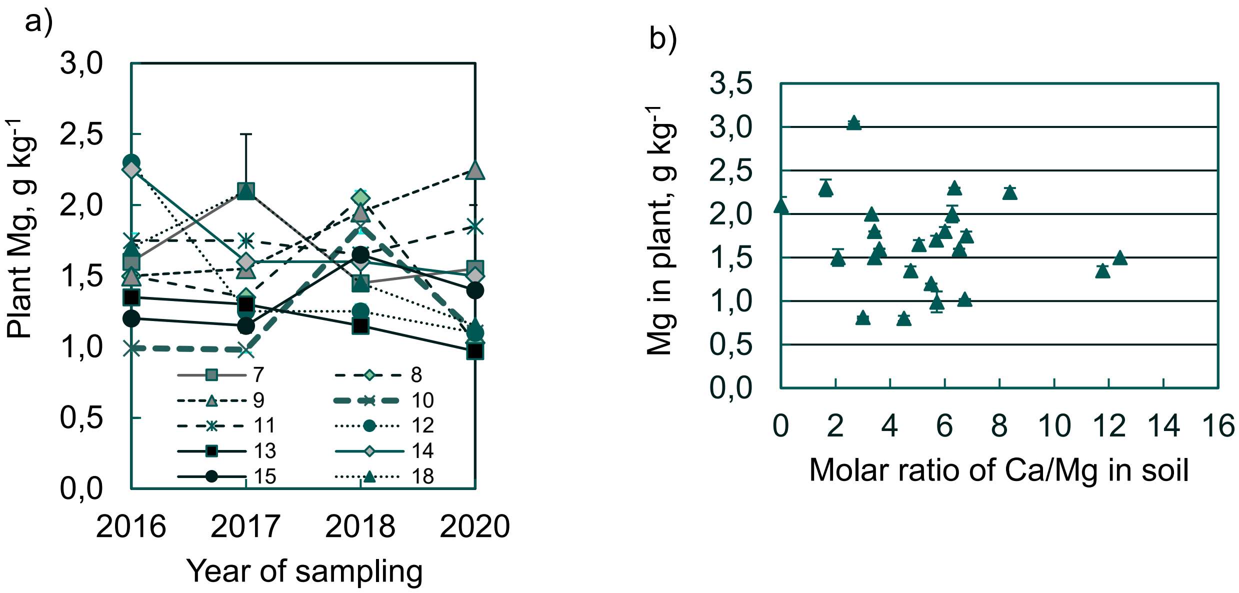

Fig. S1. Plant Mg concentrations collected from the fields amended with gypsum (a) and relationship between plant Mg concentration and the molar Ca/Mg ratio in soil (b).

References

Jansson, H., Yläranta, T. & Sillanpää, M. 1985. Macronutrient contents of different plant species grown side by side. Annales Agriculturae Fenniae 24: 139–148.

Reuter, D. & Robinson, J.B.1997. Plant Analysis: An Interpretation Manual. 2nd ed. Collingwood, VIC, Australia. CSIRO Publishing. 450 p.

Riechelman, B., Postma, R., Specken, J. & De Haan, J. 2021. Critical nutrient concentrations in arable crops; literature study on the usability of critical concentrations to diagnose nutrient deficiency and/or steer fertiliser application, Nutrienten Management Instituut BV, Wageningen, Rapport 1792.N.20. 42 p.

Sillanpää, M. 1982. Micronutrients and the nutrient status of soils: a global study. FAO Soils Bulletin 48. 444 p.

Vehviläinen, B. & Huttunen, M. 2001. Hydrological Forecasting and Real Time Monitoring in Finland: The Watershed Simulation and Forecasting System (WSFS). http://hdl.handle.net/10138/170125

Yläranta, T. & Sillanpää, M. 1984. Micronutrient contents of different plant species grown side by side. Annales Agriculturae Fenniae 23: 158–170.