The influence of gypsum treatment on the acquirement of nutrients from soils by barley

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ABSTRACT

The aim of the present paper was to determine the impact of gypsum treatment of soils on initial growth and nutrient uptake by spring barley. Topsoil from 36 different farmed fields was used for the research. Two variants were established for each soil: control – without gypsum application, and response variant – with the application of 3.3 ppm $CaSO_4.2\ H_2O$. Barley was grown on these soils for 21 days in a plant growth chamber under controlled conditions of cultivation. Concentrations of nutrients (N, NO_3^-, P, S, K, Mg, Ca, Na, Fe, Mn, Zn, Cu, B and Mo) were determined in the yield of barley shoot biomass. Paired *t*-test was used for the evaluation of results. After the gypsum treatment the yield of barley shoot biomass was significantly higher (by 15% on average) and nitrogen utilisation was better on all soils. The concentration of sulphur increased five times on average and Ca concentration increased by 22%. Significant increases were measured in Mg, Mn and Cu. Insignificant differences were recorded in K, Na, Fe and Zn. The uptake of anion nutrients (P, B and Mo) was influenced significantly. The concentration of P and Mo decreased on average by 28% and 31%, respectively. B concentration was higher by 10% on average.

Keywords: soils; gypsum; nutrient uptake; barley; N; P; S; K; Mg; Ca; Na; Fe; Mn; Zn; Cu; B; Mo

The use of gypsum ($CaSO_4.2\ H_2O$) for fertilisation has a long history dating back to the ancient Greece and Rome. In Europe gypsum treatment of soils was still a widely used practice in the 18th century (Tisdale and Nelson 1975). Gypsum treatment of salinised, alkaline soils in arid areas is an old amelioration measure to displace an excessive proportion of sodium in the sorption complex. In more humid conditions of the Czech Republic the gypsum was not practically used for fertilisation in the past. But a large proportion of gypsum was applied to soils by an intensive fertilisation with simple superphosphates when two moles of calcium sulphate (gypsum) fell on 1 mole of monocalcium phosphate. Later so-called ballast-free triple superphosphates and ammonium phosphates started to be used for fertilisation, and the supply of gypsum to agricultural soils stopped. Furthermore, a radical reduction of sulphur dioxide emissions to the atmosphere from thermal power plants has minimised the sulphur supply to soils in the last decades. A negative balance of sulphur in plant production has led to a general sulphur deficiency, mainly in crops with high requirements for sulphur.

In the process of desulphurisation of pollutants from the burning of brown coal high quantities of so-called power-plant gypsum are generated, which is currently used for the production of gypsum plasterboards for the building industry. The gypsum as a source of sulphur and calcium for soil fertilisation and nutrition of farm crops is still used sporadically.

In the course of our research on sulphur in plant nutrition, after the application of ammonium sulphate we registered the by-effects on the uptake of nutrients by barley, especially phosphorus depression and boron stimulation (Matula 2004). The impact of the gypsum treatment of soils in relation to the indication of the nutrient status of soils by multi-nutrient soil tests (Mehlich 3, extraction with 0.5M ammonium acetate with addition of NH_4F, and extraction with water) was studied by Matula and Pechová (2005). The objective of our experiment was to determine the impact of gypsum application to 36 different soils (at a dose of about 2 t Ca/ha) on the growth and uptake of a complex of nutrients by barley under controlled conditions of cultivation in a plant growth chamber.

MATERIAL AND METHODS

Thirty-six soils from topsoils of agriculturally farmed fields in 22 localities of the Czech Republic were used for the study. Bulk samples of soils were air-dried and homogenized by screening through a 2-mm sieve. Three soil tests were used to evaluate the nutrient status of soils: Mehlich 3 (Zbíral 2002), water extraction of soils at a 1:5 ratio w/v (SPAC 1999), and extraction with 0.5M ammonium acetate with the addition of ammonium fluoride (Matula 1996). Table 1 shows some characteristics of the set of soils.

The set of 36 soils was divided into two subgroups of 18 soils each respecting the capacity of a plant growth chamber. Short-term (21-day) vegetation trials were established on each soil with spring barley cv. Akcent as a test plant using this scheme: C – control variant, without gypsum application; T – treated (response) variant, with the application of 0.33 g $CaSO_4.2\,H_2O$ (gypsum) per 100 g of soil. Each variant had three replications. Vegetation pot 6 cm in diameter was filled with 100 g of soil that was mixed with 80 g of coarse-grained quartz sand.

Fifteen barley seeds (after their washing and one-hour soaking in distilled water) were planted onto soil-sand mixture surface in vegetation pots and covered with 25 ml of coarse-grained quartz sand. Moistening of vegetation plots was differentiated on the basis of an experimentally determined relationship between the field water capacity of soil and the value of its cation exchange capacity (CEC) (Matula et al. 2000). The moisture content was regularly renewed according to the weight loss of vegetation pot.

Cultivation took place in a plant growth chamber with the light and temperature regime: daylight 16 h, 20°C, dark 8 h, 15°C; photosynthetically active radiation 500 μE/m^2/s. Nitrogen dose of 6 mg N/pot, as NH_4NO_3 solution, was applied jointly with watering on days 3, 7, 11, 14 and 17 since the trial establishment. Harvested barley shoots were instantly dried at 65°C.

A Milestone microwave device was used for mineralization of barley dry matter in the medium of nitric acid and hydrogen peroxide; the analysis was carried out on an ICP-OES Trace SCAN apparatus (Thermo Jarrell Ash). The content of total nitrogen and phosphorus was determined in a mineralisate of sulphuric acid with addition of salicylic acid on a San Plus System SKALAR analyser. Nitrate content in barley dry matter was determined in water extract also on a SKALAR analyser.

Statistical programme GraphPad PRISM, Ca, USA, version 3.0 and Microsoft Excel 2000 were used for experimental data processing.

RESULTS AND DISCUSSION

Plants in all soils responded to the gypsum application to soils by a significantly higher formation of shoots (Table 2). The yield of shoot biomass in the gypsum treatments was by 15% higher on average. The utilisation of nitrogen for yield formation was more efficient in soils with gypsum, which is documented particularly by a significant decrease in the nitrate concentration in plants (Table 2). The trend of dry matter yield increment was influenced by the initial level of sulphur reserve in the soil (Figure 1). Higher increments of the yield of barley shoot biomass were reached in soils with initial sulphur content in the soil below 15 ppm detected by the soil test by means of soil extraction in water. It could be naturally assumed that the sulphur application would affect mainly sulphur and calcium uptake. The concentration of sulphur in barley after the gypsum treatment of soils increased five times on average. An increase in the calcium concentration in barley was considerably lower (22% on average), and it was determined in 35 soils, except soil No. 32.

Tables 3 and 4 show the impact of the gypsum treatment on concentrations of cation nutrients. Differences in potassium, sodium, iron and zinc were insignificant. Significant differences were determined in magnesium, manganese and copper. In the whole subset of gypsum treatment the concentration of magnesium in barley shoots was by 7% higher on average and was recorded in 27 soils. A more marked increase in the concentration in barley shoots was measured in manganese in 29 soils, by 34% on average. An increase was observed in copper in 30 soils, and the concentration was by 11% higher on average. In the main cation nutrients it can be assumed that the impact of the gypsum treatment on their uptake was mainly influenced by the establishment of equilibrium between the sorption complex of soils and the liquid phase of soils after a radical supply of calcium to soils through the gypsum dose. The impact of the gypsum treatment on changes in chemistry and pH value of soils was minimal. It is not a credible argument for the uptake of trace elements, manganese and iron.

The impact of the gypsum treatment on the acquirement of anion nutrients (P, B and Mo) is

Table 1. Information about the chemistry and nutrient status of the experimental set of soils

Soil	C_{ox} (Sims and Haby 1971)	pH 0.2M KCl (1:1 w/v)	Soil test: 0.5 M NH_4-acetate (Matula 1996)							
			CEC (mmol/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	Mn (mg/kg)	P (mg/kg)	S (mg/kg)	B (mg/kg)
1	1.47	6.06	120	164	144	1997	2.51	15.2	5.7	0.25
2	1.31	5.88	128	177	213	2632	2.08	23.1	7.2	0.16
3	1.71	6.89	108	199	37	3704	1.89	4.6	3.7	0.39
4	2.32	6.80	256	821	184	3804	2.43	17.1	15.4	0.70
5	1.42	6.16	128	172	83	1993	1.43	18.3	5.1	0.32
6	2.17	6.36	186	257	163	2990	1.06	20.4	12.6	0.40
7	1.38	6.69	124	184	96	2106	2.02	15.8	7.4	0.21
8	1.86	6.13	136	133	139	2680	1.47	24.0	28.7	0.08
9	1.85	4.08	140	103	174	3018	4.55	12.3	11.9	0.02
10	2.40	5.06	160	156	211	2352	2.94	9.0	17.9	0.11
11	1.75	5.33	142	87	187	2016	2.32	4.6	5.9	0.12
12	1.84	4.94	135	271	62	2036	3.83	21.8	9.6	0.07
13	1.60	6.63	120	121	50	2024	1.48	17.2	4.7	0.24
14	2.55	5.35	179	435	172	2636	3.74	9.6	13.5	0.27
15	1.60	5.84	126	303	156	2002	2.99	13.8	8.9	0.14
16	1.50	5.67	103	175	124	2192	2.69	21.7	5.3	0.19
17	1.20	4.84	109	122	151	1994	3.17	12.9	5.2	0.16
18	1.72	6.38	116	278	59	2574	3.78	27.2	16.9	0.10
19	2.10	5.09	136	184	108	2006	3.13	17.6	12.0	0.12
20	2.61	5.90	113	162	91	1544	4.04	8.1	15.5	0.10
21	2.89	5.73	133	315	73	2322	3.95	24.1	13.2	0.11
22	2.49	5.05	146	334	128	1874	2.91	23.6	18.7	0.10
23	1.91	5.62	123	162	76	1953	3.13	16.2	8.1	0.09
24	1.96	6.22	151	166	195	1951	1.22	9.1	16.9	0.10
25	2.33	5.76	135	229	99	2184	2.31	21.2	14.7	0.09
26	2.18	5.96	117	215	103	2622	2.89	44.4	29.3	0.15
27	2.30	5.76	113	266	103	2442	2.72	57.8	18.5	0.13
28	2.11	5.43	219	222	430	2786	1.94	5.5	8.3	0.15
29	1.73	5.32	103	164	101	1740	5.13	20.6	11.1	0.09
30	2.09	5.60	116	131	76	1940	4.13	15.5	13.3	0.08
31	1.63	5.60	135	115	120	1967	2.00	9.3	11.4	0.16
32	2.20	6.94	124	85	22	1592	2.00	3.2	23.3	0.35
33	2.37	6.10	112	174	87	2348	3.33	30.4	26.0	0.10
34	1.70	5.35	97	82	131	1887	2.56	14.4	9.1	0.01
35	2.14	4.50	105	236	99	1229	11.93	34.1	19.5	0.05
36	2.10	5.83	95	532	95	1614	2.07	35.8	10.5	0.16

Table 2. Statistical evaluation of experimental results of barley shoots

Statistics	Yield of dry matter (g/pot)		N-concentration (g/kg)		N-uptake (mg/pot)		Nitrate concentration (g N/kg)	
	control	treatment	control	treatment	control	treatment	control	treatment
Minimum	0.5110	0.6250	24.87	25.27	18.38	21.95	0.610	0.130
Median	0.7175	0.8225	33.11	31.51	23.83	26.66	2.815	1.820
Maximum	0.9340	1.0880	44.54	38.73	29.70	32.7	6.600	4.620
CV%	14.17	13.92	13.01	11.00	12.79	10.25	54.71	79.54
Paired *t*-test, two-tailed, number of pairs = 36								
P value	$P < 0.0001$***		0.021**		$P < 0.0001$***		$P < 0.0001$***	
Difference significance	yes		yes		yes		yes	
Mean of differences	–0.1081		1.832		–2.194		1.134	
95% CI	–0.1298 to –0.08636		0.7104 to 2.954		–2.772 to –1.615		0.7985 to 1.469	
R squared	0.7452		0.2393		0.6291		0.5740	

documented in Table 5. Phosphorus uptake was influenced most markedly. The concentration of phosphorus in barley shoots was by 28% lower on average in soils with the gypsum treatment. The reduction in phosphorus concentration cannot be explained by a dilution effect as a result of growth stimulation by the gypsum application because the uptake of phosphorus by barley shoots was also lower, by 18% on average. In Figures 2 and 3 the initial reserve of phosphorus in soils (detected by the soil test with water extraction) is related to the concentration and uptake of phosphorus by barley shoots. The graphs clearly illustrate the uncoupling of trend curves between control and response variants with gypsum application. In our previous paper (Matula and Pechová 2005) we tried to determine the impact of gypsum application on phosphorus extractability from soils

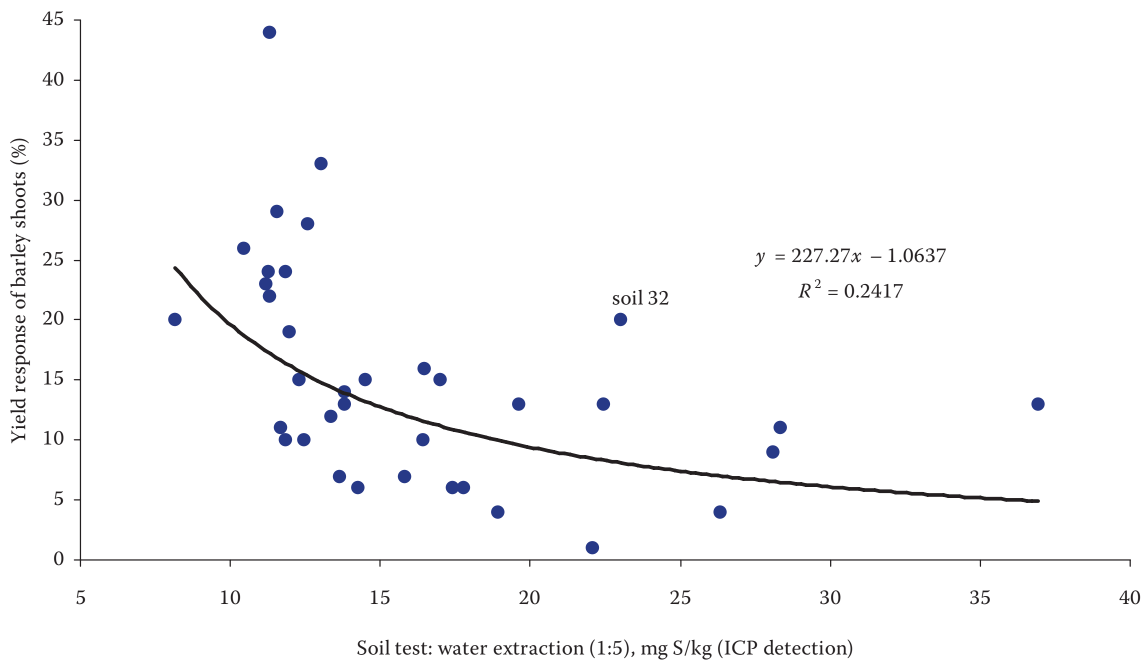

Figure 1. The yield response of barley shoots to the gypsum treatment of soils

Table 3. Statistical evaluation of experimental results, nutrient concentration in barley shoots

Statistics	K-concentration (g/kg)		Mg-concentration (g/kg)		Ca-concentration (g/kg)		Na-concentration (g/kg)	
	control	treatment	control	treatment	control	treatment	control	treatment
Minimum	9.370	8.210	1.650	1.680	5.250	6.580	0.290	0.410
Median	22.19	20.95	2.270	2.460	7.650	9.585	0.840	0.910
Maximum	46.16	49.11	3.860	3.790	15.71	13.14	4.110	3.320
CV%	37.01	43.33	20.69	21.44	24.61	17.72	72.66	59.86
Paired *t*-test, two-tailed, number of pairs = 36								
P value	0.1361		0.0004***		*P* < 0.0001***		0.1147	
Difference significance	no		yes		yes		no	
Mean of differences	–0.9236		–0.1581		–1.736		–0.04944	
95% CI	–2.153 to 0.3062		–0.2401 to –0.0760		–2.256 to –1.216		–0.1115 to 0.0127	
R squared	0.06236		0.3046		0.5677		0.0696	

by three soil tests. Water extraction after the gypsum treatment of soils indicated lower values of extractable phosphorus by 69% on average than did ICP detection and by 58% compared to the colorimetric detection on the Skalar analyser. Lower values of extractable phosphorus after gypsum application were also determined by the soil test with 0.5M NH_4-acetate and addition of NH_4F: on average by 11% and 14%, respectively, compared to ICP detection and Skalar detection. The soil test Mehlich 3 did not show any significant differences in colorimetric detection of phosphorus after the gypsum treatment. But in ICP detection of phosphorus the values in the extract were by 31% higher on average.

Nevertheless, the results demonstrate the influence of gypsum application on the level of water-soluble phosphorus in the soil. The lower acquirement of phosphorus by barley after the gypsum treatment could be a result of a depression in soluble P in the soil. But this conclusion in not in agreement with Matula (2004): after the

Table 4. Statistical evaluation of experimental results, nutrient concentration in barley shoots

Statistics	Mn-concentration (mg/kg)		Fe-concentration (mg/kg)		Zn-concentration (mg/kg)		Cu-concentration (mg/kg)	
	control	treatment	control	treatment	control	treatment	control	treatment
Minimum	20.86	34.50	38.40	47.30	18.51	18.20	4.330	4.570
Median	44.89	53.93	58.05	61.65	35.46	30.93	5.955	6.645
Maximum	107.4	202.1	114.2	112.8	81.35	220	9.890	10.610
CV%	33.17	48.42	23.18	20.45	35.42	87.15	21.54	20.40
Paired *t*-test, two-tailed, number of pairs = 36								
P value	0.001**		0.0539		0.9409		*P* < 0.0001***	
Difference significance	yes		no		no		yes	
Mean of differences	–15.32		–5.142		0.3136		–0.6375	
95% CI	–23.99 to –6.648		–10.38 to 0.0937		–8.219 to 8.846		–0.8799 to –0.3951	
R squared	0.2691		0.1021		0.0002		0.4492	

Table 5. Statistical evaluation of experimental results of barley shoots

Statistics	P-concentration (g/kg)		P-uptake (mg/pot)		B-concentration (mg/kg)		Mo-concentration (mg/kg)	
	control	treatment	control	treatment	control	treatment	control	treatment
Minimum	1.610	1.230	1.000	1.070	4.270	5.440	0.320	0.270
Median	3.355	2.500	2.390	2.035	8.965	9.705	0.895	0.570
Maximum	6.100	4.370	4.630	3.790	19.03	21.33	2.180	1.650
CV%	28.24	32.36	31.18	31.08	39.33	38.47	39.26	49.09
Paired *t*-test, two-tailed, number of pairs = 36								
P value	*P* < 0.0001***		*P* < 0.0001***		*P* < 0.0001***		*P* < 0.0001***	
Difference significance	yes		yes		yes		yes	
Mean of differences	0.9961		0.4639		–0.9864		0.3097	
95% CI	0.828 to 1.164		0.3433 to 0.5845		–1.355 to –0.617		0.1904 to 0.4290	
R squared	0.8061		0.6355		0.4572		0.4428	

application of 26 ppm nitrogen to 48 soils in the form of NH_4Cl and $(NH_4)_2SO_4$ a lower acquirement of phosphorus by barley was observed in the sulphate variant in similar relations (28% in the phosphorus concentration in barley and 20% in its uptake). The inconsistence of the above-mentioned results could indicate the participation of principles of physiological character. E.g. Yadav and Yadav (1998) reported a better uptake of phosphorus in the chloride variant compared to the sulphate one.

After the gypsum treatment there was a depression in molybdenum acquirement in similar relations as in the case of phosphorus. The

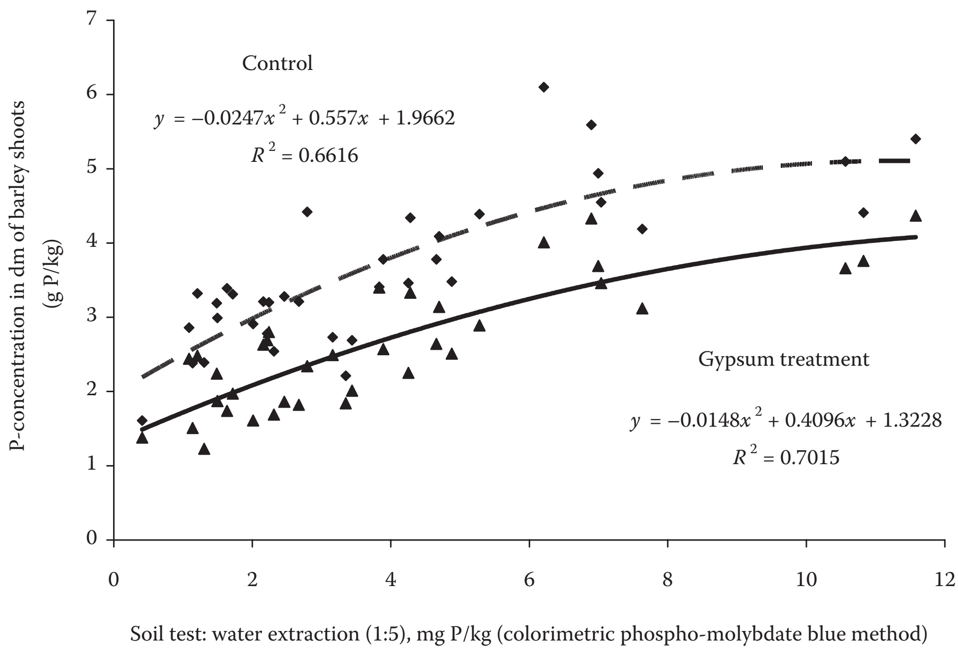

Figure 2. Relationship between the H_2O (1:5) P-soil test and the phosphorus concentration in barley shoot biomass

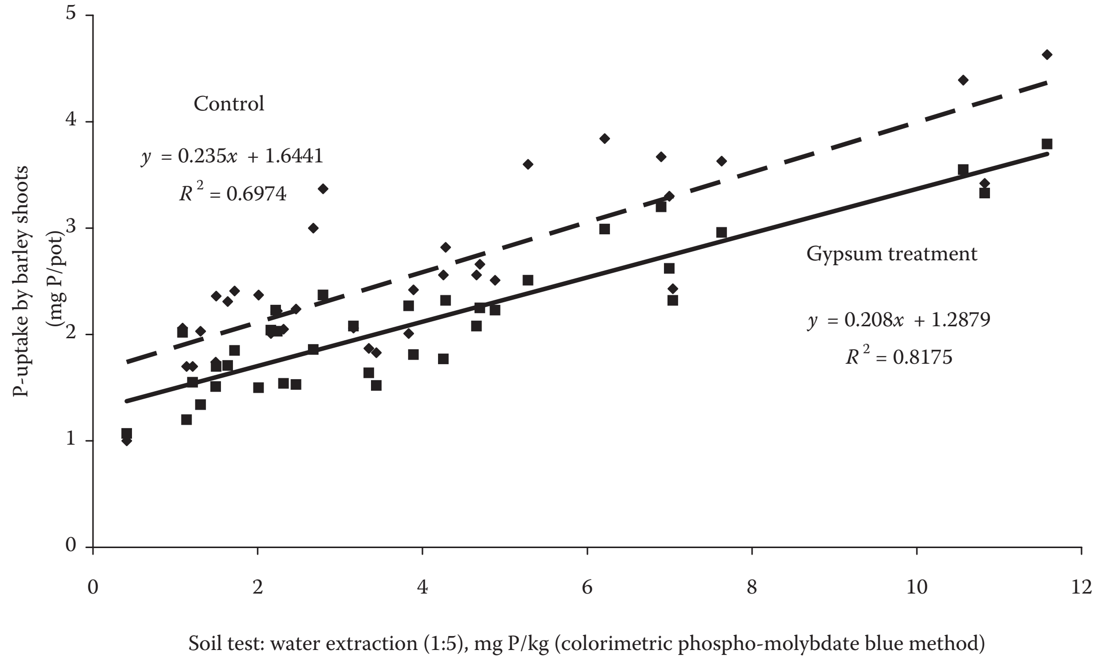

Figure 3. Relationship between the H_2O (1:5) P-soil test and the phosphorus uptake by barley shoot biomass

concentration of molybdenum in barley shoots was lower by 31% and was recorded in 34 soils. The molybdenum depression can be explained rather by the well-known antagonistic effect of sulphates on molybdenum uptake (Mengel and Kirkby 1982, Jones et al. 1991) than by the influence on molybdenum availability due to a change in soil chemistry after the gypsum application. No marked differences in the values of soil pH were observed between the gypsum treatment and the control.

Paired *t*-test proved a significance of differences between boron concentrations in barley after the gypsum application (Table 5). On average by 10% higher concentrations of boron in plants were measured after the gypsum treatment. The increased concentration of boron was detected in 30 out of 36 soils. A better acquirement of boron after the gypsum treatment could be connected with the induced lower acquirement of phosphorus after the gypsum application to soils. Jones et al. (1991) reported that the induced phosphorus deficiency increased the boron content in grapevine and strawberry leaves. A synergetic effect between boron and sulphur in mustard was described by Khurana and Chatterjee (2002). On the contrary, Sinha et al. (2003) expected a positive interaction between boron and phosphorus in mustard.

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