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Effect of forest liming in the Western Krušné hory Mts.

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ABSTRACT: In May 31, 2000, the Government of the Czech Republic, has adopted the Decision No. 532, assigning the minister of agriculture to realize liming and fertilizing in the Krušné hory Mts. and Orlické hory Mts. Based on the decision, in 2000–2003, liming of forest stands was done, at the area of 34,000 ha. Changes of soil and leaf chemistry two years after liming were studied in the Western Krušné hory Mts., Forest administration Horní Blatná. Slight pH increase layer was stated both in the humus layer, and in upper horizons of mineral soil. Increased contents of calcium and magnesium, same as nitrogen and potassium were also recorded. Content of basic cations, mainly of magnesium and calcium, in the sorption complex was increased, aluminium content was decreased. C/N ratio in the humus layer did not change, ratio of basic cations and aluminium in the humus layer was increased significantly. Analyses of the assimilation organs of spruce have proved increase of magnesium and calcium content. The increase was higher in the stands of originally lower values of these elements. While before liming, in about a half of the samples of second needle year class, magnesium was under the deficiency level, two years after liming no deficient values were recorded.

Keywords: acidification; spruce yellowing; liming; forest soils; chemical properties; base saturation

Forest soils in the Czech Republic had developed mainly on the acid, rock-forming, substrates. During the long-term period of forest utilization by man, the soils were depleted in a high amount of bio-genous elements, mainly nitrogen, calcium and magnesium. Half century lasting high deposition of the acid compounds has meant another harsh decrease of the mineral element supply.

First trials on liming have started in the Czech Republic already in the 30ies of the last century. They were of ameliorative character, and they were a part of soil preparation in forest regeneration at strongly degraded soils. The aim of aerial application of lime containing materials was to revitalize element circulation in the Scotch pine and Norway spruce stands, and to increase their growth. The results, however, did not corresponded to the expectations, and, to increase the growth, nitrogen fertilizers were used further on.

During the eighties and seventies, liming was focused on regions of high air pollution load. Most extended plots have been treated within the region of Eastern Krušné hory Mts. (Kubelka 1993), and also in other polluted regions (Table 1). The aim was to improve the unsatisfactory state of the forest soil, and to compensate really high acid deposition. At the beginning of nineties, in the period when direct impact of emission has lowered, such applications were abandoned gradually.

In 1999, in the Western part of the Krušné hory Mts., in Horní Blatná and Kraslice, vast yellowing of the forest stands has been observed, connected with the basic element, mainly magnesium and calcium, deficit in needles and forest soils (Šebková et al. 2001). Similar damage was observed also in

Table 1. Area of liming in air pollution regions of the Czech Republic in 1978–1991

Krušné hory Mts.	62,000 ha
Jizerské hory Mts.	8,000 ha
Krkonoše Mts.	7,409 ha
Orlické hory Mts.	2,800 ha

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some parts of the Orlické hory Mts. In 2000, in many localities, besides colour changes, drying off and fall of the needles was observed. Deterioration of the health state has overreached the state when the trees are still able to regenerate; there was a risk of stand density lowering, and, in some places, stand disturbance. These symptoms were typical for strong magnesium deficiency (Ende, Evers 1997). Chemical analyses of needles have proved significant deficit of some nutrients, mainly magnesium, calcium, and zinc, in the stands damaged. Very low supply of these elements has been proved also in the forest soils.

In May 31, 2000, the Government of the Czech Republic, has adopted the Decision No. 532, assigning the minister of agriculture to realize liming and fertilizing in the Krušné hory Mts. and Orlické hory Mts. Based on the decision, in 2000–2003, liming of forest stands was done, at the area of 34,000 ha, and fertilizing by liquid and powder fertilizers at 13,000 ha.

The area for liming is selected by the forest owners, based on the instructions by Forestry and Game Management Research Institute and Ministry of Agriculture of the Czech Republic. Suitability of these plots is considered by Forest Management Institute from the typology viewpoint. Selection of the plots has to be agreed by the Nature Protection authorities.

For the treatment dolomite lime was used of minimal content of MgO 17.4% and fraction granularity max. 2 mm. Liming of the total dose of 3 t/ha was done aerially, using the small crafts and helicopters.

Effect of the liming, done in 2000–2004, was systematically controlled. In the stands, included in liming, samples of humus and mineral soil are taken before treatment – 1 sample spot per about 100 ha. For needles one sample is taken per about 300 ha of the plot treated. Next sample taking is supposed to be done in two, five, and ten years after the treatment.

In this paper, changes of the basic chemical parameters of soil and needles are evaluated, treated in 2000 and 2001, in the Western part of the Krušné hory Mts., within the forest administration Horní Blatná (state forest), and in the community forests of Boží Dar, and Jáchymov.

METHOD

In 2000–2001, within the region investigated, liming was done at 3,183 ha (Table 2). In these localities soil samples were taken in 39 stands, and Norway spruce needle samples (*Picea abies* L. Karst.) in 14 stands.

Table 2. Area of liming within the localities investigated in 2000–2001

	2000	2001
LS Horní Blatná (ha)	1,577	1,073
OL Boží Dar (ha)	105	0
ML Jáchymov (ha)	0	428
Total (ha)	1,682	1,501

Soil samples before liming have been taken in May 2000, and 2001, control samples in May 2002, and 2003 respectively. In three spots in each stand mixed samples of humus (FH), upper mineral horizon, enriched in humus (A), and next mineral horizon up to 30 cm (B) were taken. In the samples an active pH–pH(H_2O), and exchangeable pH(KCl) was stated. In 2000–2002, nitrogen contents were stated by kjeldahlization, spectrometrically, the contents of oxidable carbon by iodo-metrical titration after oxidation by the chlorine-sulphur mixture. In 2003 the total C and N contents were stated by the CNS element analyzer (Leco). The content of exchangeable elements was stated in the elution by amonnium chloride, total element contents by aqua regia and following spectro-photo-metrical stating by ICP-OES. Exchangeable phosphorus was analyzed spectrofotometrically after solution in HCl + H_2SO_4. Mixed needle samples were taken at ten trees in each stand, of the upper, sun-exposed part of the crown. For technical reasons they were taken preferably in the young stands (less than 50 years). Samples of the first and second needle year class were analyzed. Sample decomposition was done in the micro-wave oven, stating of individual elements same as in the soil samples.

Significance of differences in individual parameters before and after liming was tested by the *t*-test a multiplied comparison (Dunn) at the 95% reliability level, using the UNISTAT programme.

RESULTS AND DISCUSSION

Global results of the chemical analyses of soil are presented in the Table 3. Changes in soil acidity and the content of exchangeable nutrients were, logically, more significant in the humus layer, and the upper mineral horizon, compared to the deeper soil layers. Decrease of acidity in all the horizons was more significant for the exchangeable pH, compared to active pH, the difference is more significant in the

Table 3. Average values of the soil chemical characteristics before liming and two years after liming

Horizon		PH (H_2O)	pH (KCl)	Ca (mg/kg)	Mg (mg/kg)	N (%)	P (mg/kg)	K (mg/kg)	BS (%)	C/N	BC/Al
FH	before liming	3.66	2.55	648.6	120.4	1.71	30.6	320.9	–	18.0	0.5
	2 years after liming	4.34	3.24	2,248.0	1,083.8	1.89	55.6	424	–	19.9	11.6
	difference	0.68	0.69	1,599.4	963.4	0.18	25.0	103.1	–	1.9	11.1
	significance	***	***	***	***	***	***	***	_	***	***
A	before liming	3.62	2.61	110.1	33	0.53	20.1	106.7	9.8	–	–
	2 years after liming	3.89	2.98	234.6	132.2	1.01	19.3	177.2	19.5	–	–
	difference	0.27	0.37	124.5	98.9	0.48	–0.8	70.5	9.7	–	–
	significance	***	***	***	***	***	no	***	***	–	–
B	before liming	3.95	2.87	42.9	13.4	0.17	34.6	44.4	5.2	–	–
	2 years after liming	4.02	3.25	39.6	19.9	0.24	19.0	46.0	5.4	–	–
	difference	0.07	0.38	–3.3	6.5	0.07	–15.6	1.6	0.2	–	–
	significance	no	***	no	***	***	***	no	no	–	–

BS – base saturation, BC/Al – (Ca + K + Mg)/Al

deeper soil horizons. The exchangeable pH(KCl) before liming was very low. Before liming, in the humus layer, 97% of the samples was extremely acid (pH(KCl) > 3), in A horizon it was 87%, and in B horizon 54% of the samples taken. The rest of the samples was still strongly acid (pH(KCl) 3–4). Two years after liming representation of the samples in the category "extremely acid" had decreased in FH to 15%, in A horizon to 51%, and in B horizon to 5%. Acidity decrease was not dramatic – all the samples were still strongly and extremely acid. Changes of exchangeable pH are significant in all the horizons sampled.

The contents of exchangeable magnesium and calcium directly contained in the ameliorative materials, have increased significantly in the upper soil horizons. Since before liming, in the A horizon, very low calcium supply was stated (< 140 mg/kg) in 79% of the samples taken, and in B horizon in all the samples, two years after liming the frequency of samples of very low calcium supply in A horizon decreased to 31%, in B horizon it decreased to 95%. Before liming, very low magnesium supply (< 20 mg/kg) was stated in 15% of the samples of A horizon, and 85% of B horizon. Two years after liming the frequency decreased to 3% in A horizon, and 51% in B horizon.

An increase of nitrogen and potassium supply is connected to their faster release of the humus layer. For nitrogen an increase is significant in all the three horizons, for potassium only in humus and upper mineral layer (A). In the B horizon the changes are less significant – nutrients released are spend by the trees, and they are not eluted to the deeper soil horizons. Potassium contents before and after liming, in mineral horizons, are ranging within medium to low supply for this element.

Compared to above mentioned elements, phosphorus contents perform differently. Two years after liming, in the humus layer, significant increase of this element was recorded, in average in 25 mg/kg, in the upper mineral horizon (A) the change was insignificant, and in the depth to 30 cm even significant decrease was recorded, in 16 mg/kg.

Base saturation in the mineral horizons was very low before liming. In the A horizon 69% of the samples was below the range of critically low base saturation of basic elements (< 10%), two years after liming it was 13% only. On the other hand, just 10% of the samples was over the border of low base saturation (30%). Fig. 1 shows, that in the sorption complex relative increase of magnesium (+5%), calcium (+3%), and potassium (+1%) ratio was recorded, in contrary, the contents of aluminium (–5%), iron (–1%), H-ions (–1%) and manganese (–1%) were decreased. In B horizon no significant changes were recorded; frequency of the samples of low base saturation was both before and after liming 90%.

In the period before liming, in the humus layer, unsatisfactory C/N ratio was find, reaching the values from 15 to 22. In such a high nitrogen saturation, there is a risk of fast humus decomposition after liming, and possible loss of some nutrients bind there (Gundersen et al. 1998; Persson et al. 1995). Two

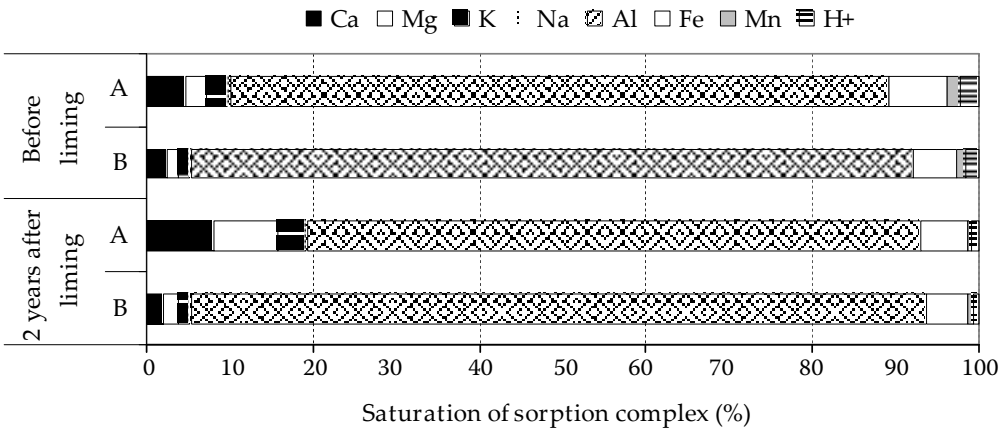

Fig. 1. Average saturation of the sorption complex of mineral horizons before and after liming

years after liming the C/N ratio was 15 to 24, and, in average, it was increased significantly.

This can be affected, however, by changes in analytical methods. The plots limed in 2000, where the samples were analyzed using the same methods, before and after liming (Nkjel, Cox) show only insignificant decrease of average C/N value, in 0.71. In contrary, the plots limed in 2001, where the contents of carbon and nitrogen were analyzed by the element analyzer, two years after liming, show significant increase of C/N ratio, in 4.04. Based on above presented data, it can be supposed, that no significant changes in C/N ratio occurred, serious evaluation has to be based on comparing of the two analytical methods, however.

The molar ratio of basic cations to aluminium has increased significantly in the humus layer (Ca + K + Mg)/Al, signalizing decrease of toxicity of this metal for the root system of the tree species.

Results of chemical analyses of assimilation organs are presented in the Table 4. It is obvious, that provable increase of element content can be proved only with some, before rather deficit elements.

Calcium contents, with the exclusion of one sample only, in the current- and one-year old needles, were over the level of deficiency (1,500 mg/kg). Two years after liming, in one-year old needles calcium content was increased, only for the current-year needles the increase was significant, however. As shown in the Fig. 2, higher increase was recorded in the stands of originally lower Ca contents in needles. In contrary, in the stands, showing calcium content in the second needle year class higher than 5,000 mg/kg, it was even decreased.

Magnesium contents in the current-year needles were under the deficiency level (700 mg/kg) only in two cases. In the one-year old needles a half of all the samples taken was deficit. Two years after liming, significant increase of Mg was recorded in the one-year old needles. Same as with calcium, more significant increase was observed in the stands of originally lower contents of Mg (Fig. 3), thus two

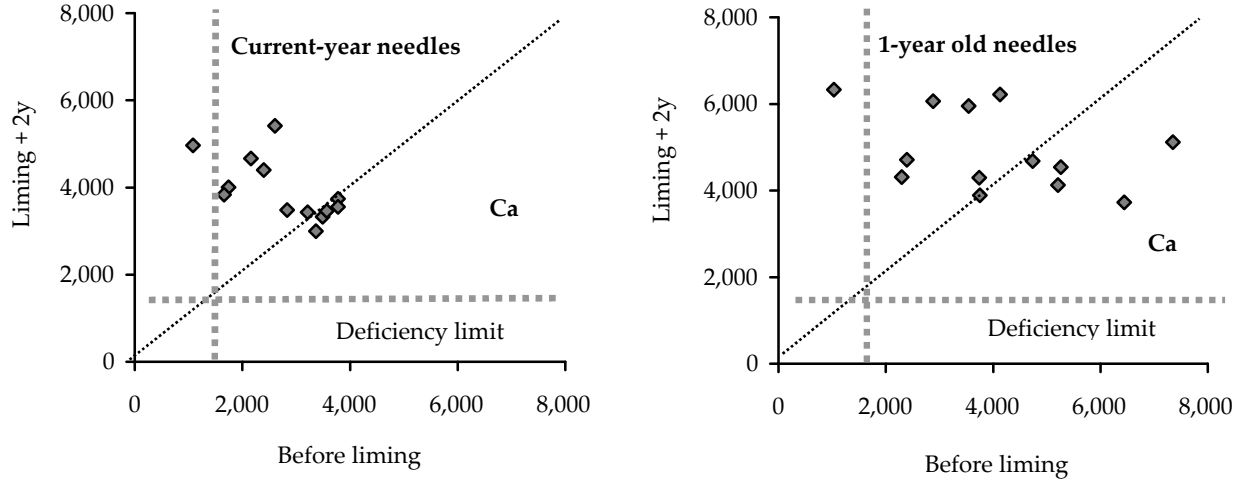

Fig. 2. Shift of calcium content in individual stands, in the first and second needle year class, before and two years after liming

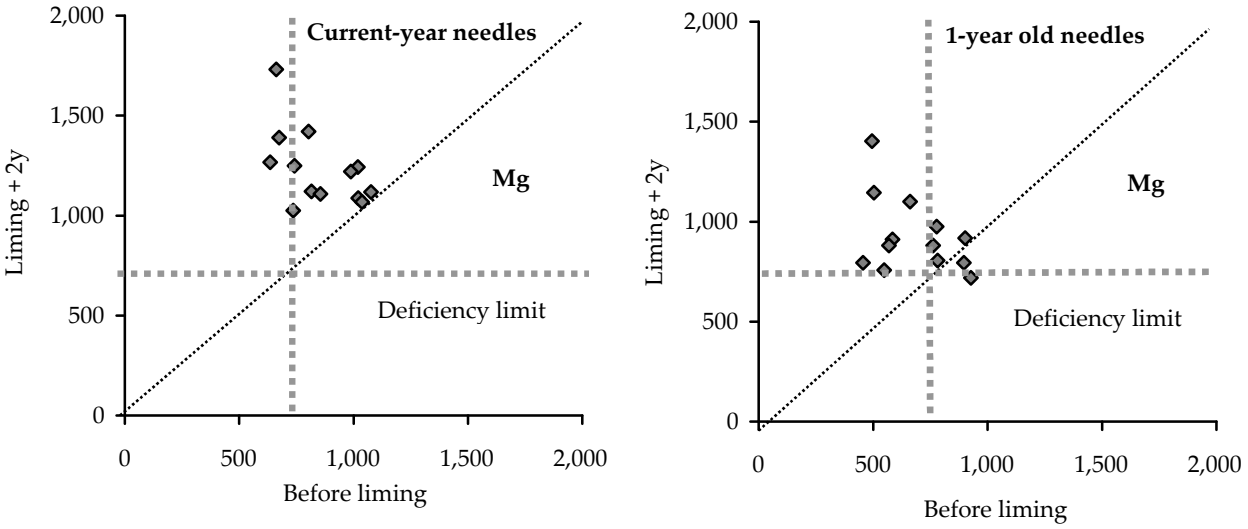

Fig. 3. Change of Mg content in individual stands, in the first and second needle year class, before liming and two years after it

years after liming no magnesium deficiency was recorded, although in many cases the magnesium content was of limit value. In the stands, where magnesium contents in the second needle year class were 900 mg/kg and more, in repeated sampling stagnation was recorded, or even magnesium decrease.

For the other main nutrients an increased content was recorded in the current- and one-year old needles, however, it was not significant in any case. Significant increase was recoded also for zinc, in the current-year needles. Decrease of manganese and aluminium contents in the two-needle year classes is another aspect of interest. It can be connected to partial substitution of these elements in the sorption complex in mineral soil. Changes for these elements are statistically insignificant, however.

CONCLUSION

Two years after liming, in the soils of Western Krušné hory Mts., slight pH increase was stated both in the humus layer, and in upper horizons of mineral soil. Contents of calcium and magnesium, same as nitrogen and potassium, were also recorded. The changes are visible mainly in the humus layer and in the upper mineral horizon, in mineral horizon up to 30 cm they are less visible – it can be supposed that nutrients were not leached of the humus layer. Content of phosphorus was decreased in mineral horizons, in contrary. Content of basic cations, mainly of magnesium and calcium, in the sorption complex were increased, aluminium content was decreased. However, base saturation, in most of the cases, is still lower than 20% in the upper

Table 4. Average element contents in needles before liming and two years after it

Needles		Ca (mg/kg)	Mg (mg/kg)	N (%)	P (mg/kg)	K (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Al (mg/kg)
Current year	before liming	2,802	861	1.44	1,741	6,551	27.6	405	102
	2 years after liming	3,943	1,234	1.46	1,862	6,858	35.5	378	83
	difference	1,141	373	0.02	121	307	7.9	–27	–19
	significancy	***	***	no	no	no	***	no	no
1 year-old	before liming	4,201	691	1.30	1,509	6,076	27.2	520	166
	2 years after liming	4,920	929	1.39	1,670	6,381	28.2	490	125
	difference	719	238	0.09	161	305	1	–30	–41
	significancy	no	***	no	no	no	no	no	no

mineral horizon, in the depth of 30 cm no changes observed by now. C/N ratio in the humus layer did not change, most probably, however, comparability of the laboratory methods is to be verified. Ratio of basic cations and aluminium in the humus layer was increased significantly.

Analyses of the assimilation organs of spruce have proved increase of magnesium and calcium content. The increase was higher in the stands of originally lower values of these elements. While before liming in about a half of the samples of second needle year class magnesium was under the deficiency level, two years after liming no deficient values were recorded.

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Účinnost vápnění lesních porostů v západním Krušnohoří

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ABSTRAKT: 31. května 2000 přijala vláda ČR usnesení č. 532, které uložilo ministrovi zemědělství provádění vápnění a hnojení v lesích Krušných hor a Orlických hor. Na základě tohoto usnesení bylo v letech 2000–2003 provedeno vápnění lesních porostů na 34 000 ha a hnojení kapalnými i sypkými hořečnatými hnojivy na 13 000 ha. V západním Krušnohoří jsme studovali změny chemismu půdy a asimilačních orgánů dva roky po aplikaci vápnění. V půdách západního Krušnohoří došlo v té době k mírnému nárůstu pH v humusu i ve svrchních vrstvách minerální půdy, k nárůstu obsahu vápníku a hořčíku v půdě i k navýšení obsahu dusíku a draslíku. V sorpčním komplexu se zvýšilo zastoupení bazických kationtů, zejména hořčíku a vápníku, na úkor hliníku. V humusu se nezměnil poměr C/N, poměr bazických kationtů k hliníku v humusové vrstvě se výrazně zvýšil. Analýzy asimilačních orgánů smrku prokázaly nárůst hořčíku a vápníku. K vyššímu nárůstu došlo u porostů s původně nízkými hodnotami těchto prvků. Zatímco před vápněním se polovina vzorků druhého ročníku jehličí pohybovala pod hranicí deficience výživy hořčíku, dva roky po vápnění nebyly deficitní hodnoty zaznamenány.

Klíčová slova: acidifikace; žloutnutí smrku; vápnění; lesní půdy; chemické vlastnosti; saturace bázemi

V roce 1999 se v západním Krušnohoří v oblasti Horní Blatné a Kraslic projevilo rozsáhlé žloutnutí lesních porostů spojené s deficitem bazických prvků – zejména hořčíku a vápníku v jehličí a v lesních půdách. Obdobná poškození byla pozorována i v některých částech Orlických hor. Na jaře 2000 již na řadě lokalit docházelo kromě barevných změn k usychání a k odumírání starších ročníků jehličí. Zhoršování zdravotního stavu překročilo hranice, kdy mohou stromy přirozeně regenerovat, a hrozí riziko prořeďování, na některých místech až rozvratu porostů.

31. května 2000 přijala vláda ČR usnesení č. 532, které uložilo ministrovi zemědělství provádění vápnění a hnojení v lesích Krušných hor a Orlických hor. Na základě tohoto usnesení bylo v letech 2000–2003 provedeno vápnění lesních porostů na 34 000 ha a hnojení kapalnými i sypkými hořečnatými hnojivy na 13 000 ha.

Vápnění prováděné v letech 2000–2004 podléhá systematické kontrole účinnosti. V porostech zahrnutých do aplikací vápence jsou před vlastním zásahem odebírány vzorky humusu a minerální půdy v hustotě jedno odběrové místo na asi 100 ha.

Pro jehličí je prováděn jeden odběr na přibližně 300 ha ošetřované plochy. Další odběry jsou prováděny (plánovány) dva, pět a deset let po aplikaci. V příspěvku jsou hodnoceny změny základních chemických parametrů půd a jehličí na plochách vápněných v roce 2000 a 2001 v oblasti západního Krušnohoří na území lesní správy Horní Blatná, Obecních lesů Boží Dar a Městských lesů Jáchymov.

Celkové výsledky analýz chemických vlastností půd jsou uvedeny v tab. 3. Změny v kyselosti a obsahu přístupných živin se logicky výrazněji projevily v humusové vrstvě a ve svrchním minerálním horizontu než v hlubších vrstvách půdy. Pokles kyselosti půdy ve všech horizontech je výrazněji patrný pro výměnné pH než pro pH aktivní. Snížení kyselosti nebylo příliš razantní – všechny vzorky zůstaly v kategorii silně kyselé a velmi silně kyselé. Změny výměnného pH jsou signifikantní ve všech odebíraných horizontech.

Obsahy přístupného vápníku a hořčíku v povrchových horizontech významně vzrostly. Zatímco v odběrech před vápněním byla v horizontu A zjištěna velmi nízká zásoba vápníku (< 140 mg/kg) u 79 % vzorků a v horizontu B u všech vzorků, dva roky po vápnění se četnost vzorků s velmi nízkou zásobou Ca v horizontu A snížila na 31 %, v horizontu B ovšem pouze na 95 %. Velmi nízkou zásobu hořčíku (< 20 mg/kg) vykazovalo před vápněním 15 % vzorků horizontu A a 85 % vzorků horizontu B. Dva roky po vápnění se tato četnost snížila na 3 % u horizontu A a na 51 % u horizontu B.

Saturace bázemi v minerálních horizontech se v období před vápněním pohybovala na velmi nízké úrovni. V horizontu A spadalo 69 % vzorků do oblasti kriticky nízké saturace bazickými prvky (< 10 %), dva roky po vápnění to bylo již jen 13 %. Na druhou stranu pouze 10 % vzorků se dostalo nad hranici nízké saturace bázemi (30 %). V horizontu B nebyly zaznamenány významné změny.

V humusu byl v období před vápněním zjištěn nepříznivý poměr C/N, který dosahoval hodnot od 15 do 22. Při tak vysokém nasycení dusíkem hrozí v případě vápnění zrychlený rozklad humusové vrstvy a ztráta některých v něm poutaných živin. Dva roky po vápnění se hodnota poměru C/N pohybovala od 15 do 24 a v průměru významně stoupla. Tento fakt však bude pravděpodobně způsoben změnou analytických metod. Plochy vápněné v roce 2000, kde byly vzorky před vápněním i po vápnění analyzovány stejnými metodami (Nkjel, Cox), vykazují nevýznamné snížení průměrné hodnoty C/N o 0,71, zatímco plochy vápněné v roce 2001, kde byly obsahy uhlíku a dusíku dva roky po vápnění analyzovány na elementárním analyzátoru, vykazují signifikantní nárůst poměru C/N o 4,04.

V humusové vrstvě výrazně narostl molární poměr bazických kationtů k hliníku (Ca + K + Mg)/Al, což signalizuje snížení toxicity tohoto kovu vůči kořenovému systému dřevin. Dva roky po vápnění došlo rovněž k významnému nárůstu obsahu vápníku a zejména hořčíku v jehličí smrku.

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