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The effect of slow-release fertilizers on the soil environment of spread windrows in the Krušné Hory Mts.

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Abstract

Pecháček J., Vavříček D., Kučera A., Dundek P. (2017): The effect of slow-release fertilizers on the soil environment of spread windrows in the Krušné Hory Mts. J. For. Sci., 63: 331–338.

The current revitalization of forest ecosystems in the Krušné Hory Mts. is carried out through: (*i*) spreading line windrows, (*ii*) chemical amelioration. The aim of this research consisted in: (*i*) assessing basic pedochemical characteristics of spread windrows, (*ii*) testing the effect of slow-release fertilizers from the Silvamix® series and dolomitic limestone on the root ball zone soil five years after application. The results of this study suggest that spread windrows are a suitable environment for forest species: with the only risk being extremely low P concentrations. Our results further show an increase in the amount of soil macrobioelements in the case of Silvamix® R and Silvamix® Forte, namely P over 125 and 85%; Mg^{2+} over 84 and 108%; base saturation (BS) over 44 and 40.7%, respectively, compared with a control. Having applied dolomitic limestone, an increase of BS (by 88%), Mg^{2+} (by 250%) and Ca^{2+} (by 37%) was observed; there was a reduction in the level of mobile Al^{3+} (by 25%) compared with the control. Stromfolixyl® application did not affect the chemistry of the soil environment.

Keywords: fertilization; chemical properties of soil; liming; Norway spruce; revitalization; spot amelioration

The Krušné Hory Mts. are among the areas the most significantly affected by air pollution ecological stresses in Europe. In the 1960s–90s, the air pollution situation, in synergy with climatic extremes in the eastern part of the mountains, resulted in the total disintegration of forest ecosystems (Vacek et al. 2003). The overall large-scale clear-felling of these stands allowed forest sites to be prepared using heavy machinery. The top soil horizons were considered heavily acidified and toxic, therefore, in the 1970s–80s they were raked in line windrows using dozer technologies (Podrázský et al. 2010; Pecháček et al. 2017). These measures were to facilitate and accelerate the regeneration of forest ecosystems. Altogether, approximately 10,000 ha of forests were affected; however, the exact extent is unavailable (Remeš et al. 2005).

Based on the findings of forestry research, revitalization of the soil environment through spreading the line windrows started at the beginning of the new millennium. Consequently, the soil environment was enriched with C-substances and an increase in cation exchange capacity occurred as well (Vavříček et al. 2011).

Chemical amelioration is another revitalizing method applied within these treated areas; it is characterized as measures resulting in the soil environment modification. There are changes in: (*i*) soil chemistry – soil reaction, content and ratio of elements, soil sorption complex (Røsberg et al. 2006), (*ii*) biological activity (Aarnio et al. 2003); and also in the intensity of biochemical, decomposition and humification processes (Aarnio, Martikainen 1995).

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Within the Krušné Hory Mts. area of interest, chemical amelioration was applied using individual fertilization or large-scale liming. Individual fertilization (individually for each transplant) is the most frequently applied treatment using slow-release mineral fertilizers. Their effect on the nutrition and growth of forest tree species was studied by Remeš et al. (2005) and Vavříček et al. (2011) in the region concerned, and by Ingerslev (1997) or Podrázský and Remeš (2008) elsewhere. The fertilizer effect on the soil environment was studied only sporadically and in short intervals (Vavříček et al. 2010). Large-scale liming was applied especially in the 1980s, and in some regions also in the following decades (the extent is not clearly recorded). The short-term, but also long-term effects on the soil environment were described (Frank, Stuanes 2003; Podrázský, Ulbrichová 2003; Šrámek et al. 2003; Borůvka et al. 2005).

In light of the foregoing facts, an experiment was arranged on the Špičák research plot; a completely scarified area where the organomineral material was later spread in a period of 20–30 years. Slow-release fertilizers and dolomitic limestone were individually applied to Norway spruce transplants. The soil there was sampled after five years and basic pedochemical characteristics were analysed.

The aim of this study is to answer the following questions:

(1) What are the basic pedochemical characteristics of spread windrows?
(2) Can individual fertilization using slow-release fertilizers and dolomitic limestone affect the soil environment five years after application?

MATERIAL AND METHODS

The research investigation was carried out on the Špičák research plot (885 m a.s.l.) situated in the beech-spruce altitudinal vegetation zone of the Krušné Hory Mts., in the borderland between the Czech Republic and Germany (50°49'67"N, 13°23'67"E). The average annual precipitation in the area fluctuates within 900–1,200 mm and the mean annual temperatures fluctuate between 2.7 and 5°C. The plot is located on a slight north-facing slope, the soil type, Haplic Podzol (FAO 2015), is developed on muscovite mica.

The plot's revitalizing phase was carried out in 2003 and the existing substitute stands of six working sectors were chipped; the organomineral material from current windrows was spread in a 15–20 cm thick layer. A new pseudo-topsoil horizon was created in this way, consisting of 20–30% of the humus of the fine-grained soil (Vavříček et al. 2008). In 2004, single working sectors were reforested with Norway spruce (*Picea abies* (Linnaeus) H. Karsten); those were four-year-old (2 + 2) bare-root transplants. After that, each of the six working sectors was divided into five regular rectangular plots with 50–60 transplants on each. Each working sector was treated with:

(1) tablet fertilizer Silvamix® Forte – SF (ECOLAB Znojmo, spol. s.r.o., Czech Republic);
(2) tablet fertilizer Silvamix® R – SR (ECOLAB Znojmo, spol. s.r.o., Czech Republic);
(3) Stromfolixyl® – STR (ECOLAB Znojmo, spol. s.r.o., Czech Republic);
(4) dolomitic limestone – DL (Krkonošské vápenky Kunčice, a.s., Czech Republic);
(5) untreated plot – control (C).

Therefore, each treatment is found in six replications. Fertilizers were applied at the beginning of the vegetation period which followed the spreading of line windrows. Tableted fertilizers were spot-applied to each individual transplant. Using a planter, fertilizers were incorporated 3–5 cm deep so that no fertilizing substance could be lost, particularly N, because of biochemical reactions and its volatilization. DL was separately applied as a spot powder sprinkling to each transplant as well. Fertilizers and DL were evenly layered within the area under the transplants' crowns; the elemental composition and applied doses are presented in Table 1.

Soil samples were collected the 5th year after the fertilizer application. The organomineral matrix was sampled from each plot: two composite samples were always taken from the root ball zone. One composite sample was created by blending material taken from the root zone of three transplants. Altogether twelve composite samples were taken from each treatment (including C).

Laboratory work covered the analyses of pH_{H_2O} and pH_{KCl} using a pH-meter (INOLAB, spol. s.r.o., Czech Republic) with combined glass electrode (soil/H_2O or 1M KCl = 1:2.5), H^+ concentration applying the principle of dual pH measurements (Adams, Evans 1989), and available mineral nutrients (Ca^{2+}, Mg^{2+}, K^+) from the Mehlich II leachate by an atomic adsorption spectrophotometry method (Mehlich 1978) in $mg\cdot kg^{-1}$. P content was determined spectrophotometrically in a solution of ascorbic acid, H_2SO_4 and Sb^{3+}. Oxidizable organic carbon (C_{ox}) was detected by the endothermic extraction in a chromosulphuric mixture. There was a surplus of a combustion mixture, and

Table 1. Composition of applied fertilizers and their dosage

Type of fertilizer	Content of individual components (%)					Fertilizer dosage for one transplant	Nutrient quantity (kg) in a fertilizer dosage per hectare*				
	N	P_2O_5	K_2O	CaO	MgO		N	P	K	Ca	Mg
SF	17.50	17.50	10.50	–	9.00	(5 tablets à 10 g)	35.00	15.28	17.43	–	10.84
SR	10.00	7.00	18.00	–	7.50	(5 tablets à 10 g)	20.00	6.10	29.90	–	9.04
STR	11.00	0.80	5.40	15.10	8.80	(8 tablets à 1.5 g)	5.28	0.17	2.15	5.16	2.55
DL	–	–	–	32.30	18.70	(80 g)	–	–	–	73.90	36.08

SF – Silvamix® Forte (ECOLAB Znojmo, spol. s.r.o., Czech Republic), SR – Silvamix® R (ECOLAB Znojmo, spol. s.r.o., Czech Republic), STR – Stromfolixyl® (ECOLAB Znojmo, spol. s.r.o., Czech Republic), DL – dolomitic limestone (Krkonošské vápenky Kunčice, a.s., Czech Republic), *expected quantity for 4,000 treated individuals

the unreacted rest was determined by "dead stop" Mohr's salt titration. Determination of total nitrogen (N_t) was performed using the Kjeldahl method (Zbíral et al. 1997). Mobile Al^{3+} content was determined by Sokolov's method. Cation exchange capacity (CEC) was determined by the summation method (Eq. 1), the content of a particular cation was calculated by Eq. 2, base saturation (BS) in % was calculated by Eq. 3:

$$\mathrm{CEC} = \mathrm{K}^+ + \mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{H}^+ + \mathrm{Al}^{3+} \left(\mathrm{mmol{\cdot}kg^{-1}}\right) \quad (1)$$

$$C_{\mathrm{mmol}} = C_{\mathrm{mg}} / \left(M / \mathrm{Oxn}\right) \quad (2)$$

where:

C_{mmol} – nutrient concentration (mmol·kg^{-1}),
C_{mg} – nutrient concentration (mg·kg^{-1}),
M – element molar mass,
Oxn – nutrient oxidation number.

$$\mathrm{BS} = \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{K}^+\right) / \mathrm{CEC} \quad (3)$$

Statistical processing was done using the STATISTICA CZ program (Version 9.0, 2009). Nonparametric analysis of variance (Kruskal-Wallis test) was used; in case of a significant result, Tukey's post-hoc comparison test was applied to identify significant differences between treatments. Hypothesis validity was evaluated according to *P*-value at α = 0.05. Correlation analysis was used to evaluate relationships between individual pedochemical properties. When evaluating pedochemical characteristics of fertilized treatments and C, the abbreviation "CWC" is used, i.e. compared with control. The score C is always considered as a basis (100%). Soil environment pedochemical characteristics were evaluated by Vavříček (2011); the threshold of 1,000 mg·kg^{-1} was considered toxic for Al^{3+}.

RESULTS

Soil environment of spread windrows

The results of treatment analyses C (Table 2) show that pedochemical properties of spread windrows are favourable with one exception. This soil layer is characterized by strongly to extremely acid soil reaction, high humus content with balanced C_{ox} and N_t as well as C/N ratio. Basic cation content can be characterized as high (Mg^{2+}, Ca^{2+}) or medium high (K^+) (Vavříček 2011). Considerable absolute content of basic cations corresponds to high CEC; however, BS is generally low and soil sorption complex is occupied mainly by acid cations, both H^+ and Al^{3+}. The content of the latter element is already approaching the toxic limit of 1,000 mg·kg^{-1}. The element in minimum is likely to be P, the concentrations of which oscillate within extremely low values (Vavříček 2011).

The effect of applied fertilizers

The fertilizer effect on the soil environment in the root ball zone is presented in Table 2. In terms of ANOVA, pH_{H_2O}, pH_{KCl}, P and Mg^{2+} content, CEC and BS (Fig. 1) were classified as significant parameters, despite the considerably frequent variability. As for Al^{3+} content, H_0 was narrowly rejected (*P*-value = 0.0566). Differences in C_{ox} and N_t content, C/N ratio, Ca^{2+}, K^+ and Al^3 content were classified as insignificant.

When comparing data sets in terms of pH_{H_2O}, it becomes evident that values in DL are significantly higher CWC. Lower amounts of mobile hydrogen ions can be observed in other treatments, however, without any statistical significance. A similar situation is shown for results of laboratory analyses in the case of pH_{KCl}.

Table 2. Fertilizer effect on selected pedochemical properties in the root ball zone five years after application

Soil property		SF	SR	STR	DL	C	Kruskal-Wallis test (*P*-value)
pH_{H_2O}	mean	3.97^{ab}	4.03^{ab}	4.00^{ab}	4.35^{a}	3.72^{b}	**0.0038**
	SD	0.20	0.10	0.62	0.29	0.13	
pH_{KCl}	mean	3.09^{ab}	3.18^{ab}	3.12^{ab}	3.23^{a}	2.97^{b}	**0.0167**
	SD	0.14	0.24	0.39	0.25	0.13	
C_{ox} (%)	mean	13.34^{a}	12.85^{a}	13.64^{a}	13.56^{a}	14.56^{a}	0.5703
	SD	2.79	3.23	1.78	2.4	2.99	
N_t (%)	mean	0.71^{a}	0.66^{a}	0.68^{a}	0.68^{a}	0.73^{a}	0.753
	SD	0.16	0.15	0.09	0.12	0.16	
C/N	mean	19.14^{a}	19.81^{a}	20.31^{a}	20.23^{a}	20.26^{a}	0.8504
	SD	3.18	3.61	3.58	1.92	2.7	
P ($mg \cdot kg^{-1}$)	mean	11.58^{ab}	14.08^{a}	5.20^{b}	5.20^{b}	6.25^{b}	**0.0092**
	SD	5.96	14.61	3.29	2.57	5.67	
Mg^{2+} ($mg \cdot kg^{-1}$)	mean	319.58^{ab}	283.17^{ab}	116.90^{b}	390.8^{ab}	153.25^{b}	**0.0001**
	SD	126.21	181.05	21.26	199.27	128.95	
Ca^{2+} ($mg \cdot kg^{-1}$)	mean	546.92^{a}	646.33^{a}	709.23^{a}	820.32^{a}	597.92^{a}	0.1094
	SD	126.76	639.31	545.12	324.13	294.21	
K^+ ($mg \cdot kg^{-1}$)	mean	74.33^{a}	85.92^{a}	71.50^{a}	67.40^{a}	77.25^{a}	0.5416
	SD	15.63	28.71	11.68	7.57	14.6	
Al^{3+} ($mg \cdot kg^{-1}$)	mean	847.95^{a}	874.65^{a}	965.70^{a}	767.34^{a}	990.00^{a}	0.0566
	SD	186.28	319.9	270.26	204.58	174.26	
CEC ($mmol \cdot kg^{-1}$)	mean	409.88^{a}	420.86^{ab}	430.24^{ab}	416.19^{ab}	456.01^{b}	**0.0369**
	SD	44.95	49.02	38.13	34.35	29.73	
BS (%)	mean	13.75^{ab}	14.14^{ab}	11.57^{ab}	18.42^{a}	9.77^{b}	**0.0185**
	SD	4.25	10.34	9.32	8.92	5.29	

C_{ox} – oxidizable organic carbon, N_t – total nitrogen, CEC – cation exchange capacity, BS – base saturation, SD – standard deviation, SF – Silvamix® Forte (ECOLAB Znojmo, spol. s.r.o., Czech Republic), SR – Silvamix® R (ECOLAB Znojmo, spol. s.r.o., Czech Republic), STR – Stromfolixyl® (ECOLAB Znojmo, spol. s.r.o., Czech Republic), DL – dolomitic limestone (Krkonošské vápenky Kunčice, a.s., Czech Republic), C – control (untreated plot), letters that follow mean values denote mutual statistical differences at α = 0.05 (on the basis of post-hoc multiple comparisons by Tukey's test), significant overall differences at α = 0.05 are marked in bold

When observing C_{ox} content, there are slightly lower values within all fertilized plots CWC. C_{ox} closely correlates with N_t, the content of which in individual treatments shows an identical trend; the only exception is SF where slightly higher CWC values can be observed even after five years.

Compared with C, the content of available P in SR and SF was distinctly higher. Application of these fertilizers caused the higher P amount on average by 125% (SR) and 85% (SF). The fertilizer effect was not so pronounced in case of K^+. Samples taken from SR, however, showed values higher by 12%; nevertheless, test statistics did not show this difference as significant.

The amount of Ca^{2+} and Mg^{2+} correlates very closely with pH_{H_2O}, pH_{KCl} (Fig. 2a); unsurprisingly, samples taken in DL show the highest content. Ca^{2+} content was higher by 37% (CWC). The effect of other fertilizers on Ca^{2+} content was not noticeable. Mg^{2+} amount is still strongly influenced by the addition of fertilizer substances. Compared with C, DL showed values higher by 150%, in the case of SF the values were higher by 108%. A very strong effect was also observed in SR (by 84% more CWC).

The amount of base cations is closely interlinked with dynamics of mobile Al^{3+}, these two variables show a significant negative correlation (Fig. 2b). Al^{3+} is in significant negative correlation with regard to other related parameters, such as pH_{H_2O}, pH_{KCl} or BS. A positive effect (lower value CWC) on Al^{3+} amount was observed in most fertilized treatments. In this case, STR is the only tested product which shows no effect.

BS, besides the already mentioned bond for Al^{3+}, shows a positive correlation relationship with pH; a negative relationship was also demonstrated with respect to CEC, which is closely related to organic substance content. These statistical relationships can be very generally interpreted as the following fertilization consequences: (*i*) decrease of organic substances, (*ii*) analogous reduction of exchange positions on the organomineral sorption complex (CEC decrease), (*iii*) increase of the total amount

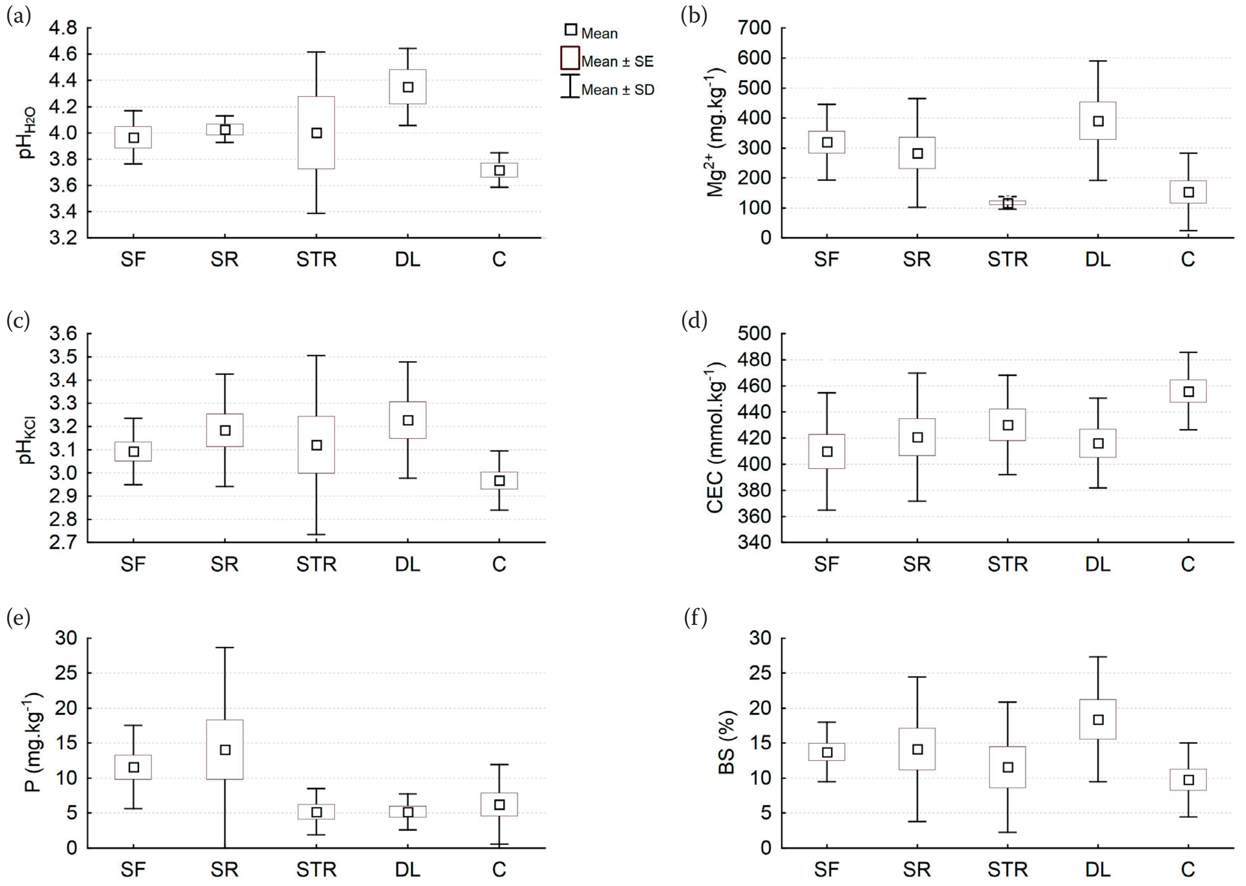

Fig. 1. The effect of fertilizers on selected pedochemical properties of soil environment in the root ball zone 5 years after application

SF – Silvamix® Forte (ECOLAB Znojmo, spol. s.r.o., Czech Republic), SR – Silvamix® R (ECOLAB Znojmo, spol. s.r.o., Czech Republic), STR – Stromfolixyl® (ECOLAB Znojmo, spol. s.r.o., Czech Republic), DL – dolomitic limestone (Krkonošské vápenky Kunčice, a.s., Czech Republic), C – control (untreated plot), CEC – cation exchange capacity, BS – base saturation

of base cations, (*iv*) BS increase. Samples from DL show higher average values by 88% (CWC); this fact was confirmed by test statistics. Distinctly higher BS values, however, not significantly, were also found in SF (by 41%) and SR (by 44%).

As already stated, most fertilizers cause a decrease of CEC levels; nevertheless, it has to be pointed out that the effect is not very pronounced. Only SF fertilizer was significant as values lower by 10% CWC were recorded there.

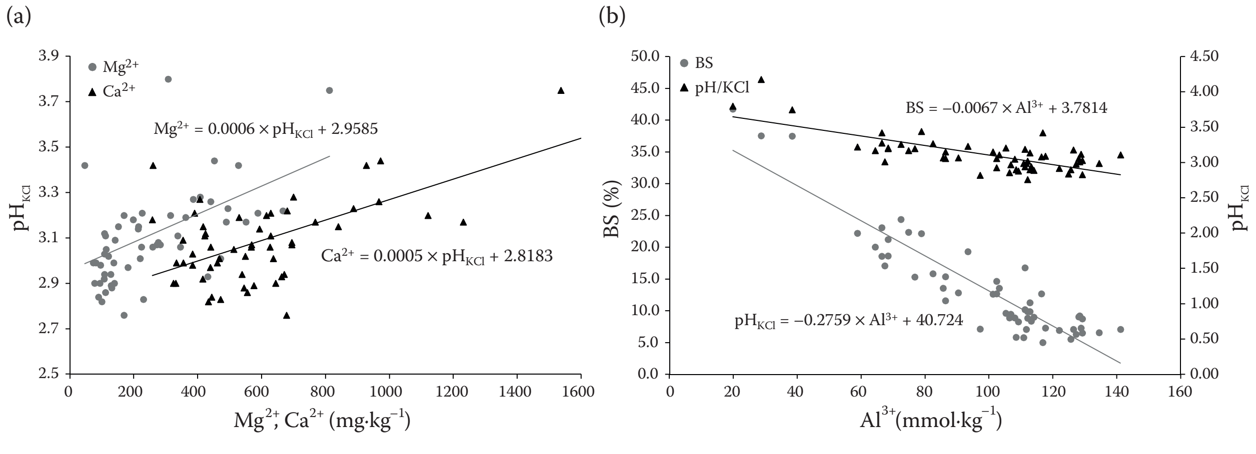

Fig. 2. Representation of correlation relationships: pH_{KCl} vs. amount of available Mg^{2+} and Ca^{2+} (a), amount of mobile Al^{3+} vs. base saturation (BS) and pH_{KCl} (b) in the root ball zone

DISCUSSION

Soil environment of spread windrows

High concentrations of Ca^{2+} and Mg^{2+} are likely related to the persisting effect of formerly performed large-scale liming. Still noticeable effects of these measures in similar climatic and soil environments were also described by Vavříček et al. (2010) or Kuneš et al. (2011).

Despite the high Ca^{2+} and Mg^{2+} content, a very to extremely low pH value was observed, which was not too surprising for the authors with respect to the above-mentioned conditions. In addition to these conditions, acidity can be induced by the high humus content and related high content of low molecular organic compounds, which cause natural acidification of the soil environment. The correlation analysis showed that decreasing pH value at Špičák increases the amount of mobile Al^{3+}, the concentration of which exceeds the toxic threshold of 1,000 $mg \cdot kg^{-1}$ in some samples; the toxic form (Al^{3+}) can destroy the fine roots and thus contribute to a decrease in forestry vitality (Bakker 1999); furthermore, it can decrease the uptake of divalent bases. This problem is known in specialized literature as a lack of Mg^{2+} and Ca^{2+} ions induced by Al^{3+} (Geburek, Scholz 1989).

Phosphorus is likely the element in minimum and its concentration fluctuates within extremely low values. The deficiency of this nutrient was also demonstrated by further studies conducted in the Krušné Hory Mts. (Fiala 2013) as well as in some other border mountains within the Czech Republic, e.g. in the Krkonoše Mts. (Vavříček et al. 2008) or Hrubý Jeseník Mts. (Pecháček 2013). From this, it can be stated that P, besides K and Mg, can further limit nutrient vitality and development of spruce stands in mountain areas in the Czech Republic (Jandl et al. 2001). Regarding the possible planning of remedial fertilization measures, the results of assimilatory organ analysis should not be forgotten either; it is a reliable indicator with regard to soil nutrient amounts in acceptable forms.

The effect of applied fertilizers

Dolomitic limestone. Excessive mineralization of organic material and related N_t losses are considered as one of the critical negatives of liming. N_t loss due to this measure was confirmed for example by studies of Podrázský and Ulbrichová (2000) or Moravčík and Ciencala (2001). Air polluted clear-cuts and open areas (Podrázský 2006) are generally classified as the most susceptible to this phenomenon. However, with respect to this study, N_t content was not affected and it is consistent with results presented for example by Lhotský and Vinšová (1981).

One of the major effects expected from liming, i.e. a massive increase of Mg^{2+} and Ca^{2+} concentrations, was confirmed in this experiment. Despite a longer period since the limestone application and a comparatively small supplied quantity (at a particular number of transplants, 80 g to each transplant would correspond to a dose of 320 $kg \cdot ha^{-1}$), liming was efficient. Consistent results were also confirmed by other authors (Podrázský 1992, 1993a, b; Jönsson 2000; Frank, Stuanes 2003). When conducting this research, Al^{3+} was reduced by 25%; this fact corresponds to the results of other authors (Juncker 1995).

Silvamix® Forte, Silvamix® R. Sets of samples taken from fertilized treatments showed an indistinct (SR) or very slight (SF) effect on N_t content. Five years after application, these results follow the expectation because N content in fertilizers is not too high. Similar conclusions were also described by Pecháček (2013), who tested the same types of fertilizers in upland zones of the Hrubý Jeseník Mts.

Having evaluated the time dynamics of the fertilizer effect on P content, the Vavříček et al. (2010) study can be used because the fertilizer effect is evaluated three years after application. It becomes evident from the comparison that the effect of fertilizer weakens as the time from application increases, however, it is still very pronounced. Depending on P content in the fertilizer composition, higher concentrations of this element were found CWC; SR was higher by 125%, SF was higher by 85%. Pecháček (2013) reported similar results as well.

The effect of fertilizers on soil K^+ corresponds to their composition. Five years after application, SR showed only a slight effect (by 10% more CWC), while SF effect was no longer evident. When compared with the Vavříček et al. (2010) study, it becomes evident that the SR fertilizer effect is reduced with the time that has elapsed since application (40% more K^+ amount CWC was found three years after application).

Even five years after application, fertilizers initiated higher amounts of exchangeable Mg^{2+} despite a comparatively low dose of the nutrient supplied. The long-term effect of magnesium fertilizers in similar climatic and soil conditions was mentioned in many studies, e.g. Vacek et al. (2009): they evaluated the long-term effect of magnesium fertilizer in the Šumava Mts. and observed a higher concentration of exchangeable Mg^{2+} even seven years after application. The content of extractable Ca^{2+} was not affected, as had been expected.

CONCLUSIONS

Top soils of spread windrows form a favourable environment which corresponds to site conditions. However, Al^{3+} and P can be considered risky elements. Al^{3+} concentrations reach the critical threshold of 1,000 $mg \cdot kg^{-1}$, and P amount fluctuates within extremely low values.

The lack of phosphorus can be compensated effectively and in the long term by applying the tested Silvamix® series fertilizers. After five-year application, a higher content of this element was found in SR (by 125%) and SF (by 85%) CWC. Both fertilizers initiate a pronounced increase of soil Mg^{2+} (SR by 184%, SF by 108%), BS (SR by 44%, SF by 40.7%); a decreasing effect on the soil K^+ amount (by 12%) CWC in SR was also found.

Five years from DL application changes in the soil environment were observed which are common for the liming effect mechanism. This treatment showed higher values of pH_{H_2O} (by 16%), pH_{KCl} (by 9%) and BS (by 88%) CWC. Higher values were also observed in base cations: Mg^{2+} (by 250%) and Ca^{2+} (by 37%). The individual spot liming did not affect the amount of humic substances (by C_{ox}); the level of mobile Al^{3+} was lower by 25% in this treatment.

In accordance with expectations, no effect on the soil environment was observed after the application of STR fertilizer.

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