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INITIAL FERTILIZATION IMPACT ON NORWAY SPRUCE NUTRITION AND GROWTH IN THE KRUŠNÉ HORY MTS.

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Abstract

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The aim of this study consisted in verifying the hypothesis whether the application of tableted fertilizers Silvamix® Forte, Silvamix® R, Stromfolixyl® and calcareous dolomite affected significantly the nutrition and growth of Norway spruce. In order to carry out research investigation, the experimental Suchdol locality has been selected as it represents large-scale reclaimed sites in the Krušné hory Mts. Ameliorating agents were applied using the initial spot fertilization of Norway spruce plantations. In the course of two years, activities as follows were carried out annually: (1) top shoots measurement, (2) sampling the latest needle year-class. The applied fertilizers impact on the concentrations of nutrients in needle dry matter was not significant with minor exception. Fertilizers Silvamix® Forte and Silvamix® R can be recommended to support seedlings growth in the area of interest since there had been positive effect on annual height increment found out. Calcareous dolomite showed the most favourable effect on the shoot biomass growth. Stromfolixyl® fertilizer had no effect on the annual increment; its impact on the nutrition can be characterized as insignificant since fertilized individuals showed lower phosphorus concentration in needle dry matter.

Keywords: Norway spruce, Silvamix® series fertilizers, calcareous dolomite, nutrition, top shoots length, Krušné hory Mts.

INTRODUCTION

The Krušné hory Mts. [338–1244 m a.s.l.; +5.5–2.7 °C (Culek, 1996)] are among areas most seriously damaged by air pollution ecological stresses in Europe. In the 1960s–1990s, the air polluted situation in synergism with climate extremes in the eastern part of the mountains resulted in total disintegration of forest ecosystems (Vacek *et al.*, 2003). Further overall clearfelling of these stands made possible to use heavy mechanized technique and prepare forest sites. Having applied dozer technologies in the 1980s and 1990s, the top soil horizons were scraped in line windrows; therefore, areas after such treatment showed up serious degradation (Vavříček *et al.*, 2003; Podrázský *et al.*, 2003 a). The layer of crucial significance as well as nutrition of forest woody species were removed (Remeš *et al.*, 2005; Sevink, 1997; Green *et al.*, 1993). This type of preparation method was applied to approx. 15 % of clear-cut area in the Krušné hory Mts. (Kubelka, 1992). Current revitalization of soil environment consists in spreading windrows in compliance with Vavříček *et al.* (2009) general guidelines; they had been dealing with above mentioned problems for a long time. Degraded soils in the space between windrows are enriched with organo-mineral mixture with high organic content. Having spread windrows, cation exchange capacity increased due to C-substances content increase (Vavříček *et al.*, 2006). Soil environment is further revitalized through chemical amelioration, which belongs from the beginning of pollution pressure to standard forestry measures facilitating reforestation in critical areas. This is a basic type of fertilizer applied frequently in degraded areas.

At higher altitudes, there was also applied fertilization to remove a Norway spruce yellowing, a specific type of damage, commonly referred to as "new type of forest decline". Its effectiveness had been confirmed by many experiments carried out in recent decades in the entire Central Europe such as in Austria (Jandl *et al.*, 2001; Katzensteiner *et al.*, 1992), in the Czech Republic (Lomský *et al.*, 2006; Šrámek *et al.*, 2006) or in France (Huber *et al.*, 2006; Schaaf and Huttl, 2006).

Another type of fertilization is the initial support of young seedlings in severe mountain conditions (Balcar, 2001). Most frequently, it is the initial fertilization of young spruce plantations, which is to support their growth and survival rate. Young trees grown in severe mountain conditions suffer from the post planting shock that causes significant growth stagnation and often contributes to significant losses of seedlings (Kuneš *et al.*, 2004; Grossnickle, 2005). Spot fertilizers application to vulnerable planting in the Czech Republic was dealt with by Kupka (2005), Podrázský and Remeš (2008); ground rocks were tested later on by Kuneš *et al.* (2004) or Balcar and Kacálek (2008).

This study is unique due to the fact that the effect of ameliorating substance is being tested on a research plot Suchdol [880–890 m a.s.l., forest type population (FTP) 6S], representing vast forests units with all over soil preparation. The similar topic in this area was already dealt with by Vavříček *et al.* (2011); however, there had been other preparation technology used, which resulted in different qualitative properties of soil environment (see methodology for details). It varies from other publications in the fact there is a detailed fertilizer effect on Norway spruce nutritional status assessed.

One year after the reforestation with a Norway spruce, a point application of tablet series Silvamix® and calcareous dolomite was carried out on the research plot Suchdol; the impact was being monitored for the next two years. The main objective of this work consists in verifying hypotheses as follows: (1) Do spread line windrows sites without chemical amelioration provide sufficiently nutritive environment to ensure Norway spruce plants nutrition? (2) Do applied fertilizers containing main nutrients (N, P, K, Ca, Mg) effect the nutrition of treated seedlings? (3) Can the fertilizer application cause any risk in disturbing the nutrition harmony? (4) Can any of fertilizers be recommended for operational use in regions with similar site conditions?

MATERIAL AND METHODS

The Krušné hory Mts. massif consists of northwest exposed undulated plateaus; the decline to podkrušnohorský basin is made up of a steep faulted slope facing the southeast (Demek *et al.*, 1965). Geological bedrock is made up mainly of metamorphic rocks (shales, gneiss, mica shists, etc.) and intrusive granitic rock bodies. The selected area Suchdol (403 E2) is located in Klášterec forest district (50°49′67″N; 13°23′67″E). This area is situated at an altitude of 880–890 m a.s.l.; its characteristics is north exposure and FTP 6S (*Piceeto-Fagetum mesotrophicum*) (Forest management plan 2009–2018). In this site, potential vegetation corresponds to the association *Calamagrostio-villosae Piceetum and Sphagno-Piceetum* (Culek, 1996; Neuhäuslová *et al.*, 1998). The predominant soil type is modal podzol (Šimková and Vavříček 2004 a,b; Vavříček, 2003).

During the air pollution ecological calamity, the area of interest was totally scarified using a smooth blade share and the top soil layers were scraped into longitudinal line windrows. Further, the area was afforested with blue spruce and silver birch. During the revitalizing period, the existing substitute stands within particular working sectors were chipped; further, the organo-mineral material from available windrows was spread in the approx. 15–20 cm thick layer. Thus, there was formed a pseudo-topsoil horizon with 12–15 % of the humus of the fine-grain soil (Vavříček *et al.*, 2006). [The above mentioned similar survey conducted by Vavříček *et al.* (2011) was accomplished on the research plot Špičák, which is characterized as a locality treated with more considerate scarification method, i.e. using a dozer with a dubbing blade]. Therefore, the top layers are characterized by higher humic substances content within 20–30 % (Vavříček *et al.* 2006). On the research plot Suchdol, so called interstrip zones were left between single working sectors covered with a new organic material layer: those are longitudinal strip zones where the substitute species had been left unchanged and organo-mineral material was not applied. 4 working sectors were established in Suchdol location. Single working sectors were afforested with Norway spruce (*Picea abies* /L./ Karsten) and after that they were divided into regular experimental plots of rectangular shape; each contains 50–60 bare-rooted Norway spruce transplants at the age of 4 years (2 + 2). The tableted fertilizers were applied at the beginning of the vegetation period, after the autumnal line windrows spreading. Each selected working sector had altogether five treatments specified: four of them were fertilizers treated and one was always selected as a control plot. Single areas were treated with standard tableted fertilizers Silvamix® Forte, Silvamix® R and Stromfolixyl® (produced by ECOLAB Znojmo, spol. s. r. o.) and sprinkled with calcareous dolomite. Tableted fertilizers were spot-applied, i.e. to each seedling; they were incorporated 3–5 cm deep using a planter so that loss of fertilizing substances could be avoided; in particular, nitrogen because of biochemical reactions and its volatilization. Calcareous dolomite was applied using flat powder spreading to each plant separately, within its crown cover. The quantity of substances was applied according to empirical criteria presented in Tab. I.

I: *Composition of fertilizers applied – representation of individual components*1(%), their dosage when applied to one Norway spruce seedling, the net amount of nutrient applied to one seedling*2 (g), average consumption of nutrients in spruce seedlings*

Type of fertilizer and consumption form		N*1	N*2	P_2O_5*1	P*2	K_2O*1	K*2	CaO*1	Ca*2	MgO*1	Mg*2
Silvamix Forte®	total	17.5	8.75	17.5	3.85	10.5	52.5	–	–	9	2.7
(5 tablets á 10 g)	water-soluble	7	3.5	7	1.54	8.5	42.5	–	–	–	–
Silvamix R®	total	10	5	7	1.54	18	90	–	–	7.5	2.25
(5 tablets á 10 g)	water-soluble	2.5	1.25	2.7	0.59	15.5	77.5	–	–	–	–
Stromfolixyl®	total	11	1.32	0.8	0.22	5.4	0.53	15.1	1.29	8.8	0.64
(8 tablets á 1.5 g)	–	–	–	–	–	–	–	–	–	–	–
Calcareous dolomite (80 g)	total	–	–	–	–	–	–	32.3	18.4	18.7	8.98
Nutrient consumption in spruce plant per year (g)		–	0.23	–	0.03	–	0.09	–	0.09	–	0.01

Samplings of assimilatory entity were always arranged in October, in particular, the first year before and further, the first and second year after the fertilizers application. The latest year of fully developed needles from the crown upper third of the individual in question was always sampled. 2 mixed needle samples were collected from each plot; the samples resulted from mixing samples of minimum 10 representative individuals. Therefore, totally 40 mixed samples were collected from 4 working sectors, 8 mixed samples from each fertilizer treatment. Sampled material was dried at a room temperature, after that needles were separated from twigs and samples were sent to be processed at the authorised Laboratory MORAVA s.r.o. resident in Studénka; the procedure applied followed Zbíral (1994) methodology. The content of nitrogen, phosphorus, calcium, magnesium and potassium was determined, nitrogen was determined using the coulometric method. The other nutrients were determined using extraction-spectrophotometry method.

Top shoots measurement was accomplished simultaneously with collecting leave samples.

Each individual was measured, i.e. totally 1.100 Norway spruce seedlings. The concentration of major nutrients in relevant needle year-class was determined according to Bergmann (1988) classification scale. Harmony in nutrition – concentration ratios of selected nutrients was assessed using classification limits provided by the Forest Folliar Coordinating Centre (FFCC) (Fürst, 2005) and Cape *et al.* (1990).

Statistical data processing was carried out using the program STATISTICA Cz 9.0 (StatSoft, Inc., Tulsa, USA). The data were grouped according to the fertilization treatments. The differences between variances of individual data sets were assessed using parametric analysis of variance (ANOVA). In case the assumptions were not followed, the Kruskal-Wallis test was applied. In case of rejecting zero hypothesis (H_0), the post-hoc analysis was performed in a Tukey's test. The entire statistical procedures were processed at significance level $\alpha = 0.05$.

RESULTS

The effect of fertilizers on concentration of nutrients in assimilatory organs

Main nutrients concentrations in Norway spruce needle dry matter is presented in Tab. II. The concentrations of majority of monitored nutrients of all treatments in Norway spruce needle dry matter were sufficient within the first year after afforestation and one year before the fertilizers application. The amount of nitrogen, phosphorus and calcium was at the optimum value level; potassium uptake was found slightly below the optimum limit (4.4 $g.kg^{-1}$).

The screening in the first year after the application showed the significant annual increase in terms of majority of monitored nutrients. Their amount fluctuated within optimum (potassium, magnesium) up to over-standard values (calcium, phosphorus). Nitrogen concentration in needle dry matter (17.2 $g.kg^{-1}$) can be classified as excellent. Majority nutrient uptake was higher on fertilized areas comparing to the control ones; however, the differences were not significant. Although individuals treated with calcareous dolomite showed slightly higher magnesium and calcium saturation, the null hypothesis of variances conformity with other data groups was not rejected by test statistics. Silvamix® series fertilizer application slightly affected the assimilatory organs saturation with phosphorus. The lowest nutrients foliar concentration in needle dry matter were found out on plots treated with the fertilizer Stromfolixyl® (1.9 $g.kg^{-1}$), which ANOVA classified as less significant comparing to the control one (2.4 $g.kg^{-1}$). However, in terms of nutrition viewpoint, these values are sufficient and are above the low optimum limit.

In the second year after the fertilizer application, the control showed the decrease in nutrient uptake of every monitored nutrient except potassium. Nevertheless, at the control, the amount of main nutrients in needle dry matter reached the standard (potassium) up to over-standard nutrition (nitrogen, phosphorus). The fertilizers effect was not remarkably significant either. Foliar concentration of

II: *Concentration of nutrients [N, P, K, Mg, Ca, S ($g.kg^{-1}$)] in the latest needle year-class for Norway spruce plantings within research site Suchdol in the Krušné hory Mts.*

Year	treatment		N	P	K	Ca	Mg	S
1 BA	**Control**	mean	14.81	2.08	4.45	4.44	0.97	–
		SD	1.830	0.102	0.250	0.515	0.143	–
1 AA	**K-W test**		0.1655	**0.0137**	0.5102	**0.0466**	0.1852	–
	Silvamix® Forte	mean	17.92[a]	1.98[ab]	7.81[a]	6.51[ab]	0.99[a]	–
		SD	2.015	0.178	0.662	0.826	0.197	–
	Silvamix® R	mean	20.37[a]	2.11[ab]	7.20[a]	6.62[ab]	1.11[a]	–
		SD	0.594	0.163	0.442	0.305	0.090	–
	Stromfolixyl®	mean	18.72[a]	1.87[a]	7.26[a]	5.97[a]	0.93[a]	–
		SD	1.358	0.144	0.768	0.436	0.094	–
	Calcareous dolomite Control	mean	18.72[a]	2.37[ab]	7.05[a]	7.11[b]	1.19[a]	–
		SD	1.517	0.179	0.264	0.221	0.177	–
		mean	17.24[a]	2.40[b]	7.14[a]	6.48[ab]	1.11[a]	0.96
		SD	0.942	0.092	0.289	0.211	0.075	0.037
2 AA	**K-W test**		0.7031	0.1471	0.2090	0.5725	0.5459	–
	Silvamix® Forte	mean	15.76[a]	1.73[a]	7.32[a]	4.48[a]	0.96[a]	–
		SD	1.681	0.057	0.791	0.512	0.190	–
	Silvamix® R	mean	16.11[a]	1.69[a]	8.13[a]	4.35[a]	0.81[a]	–
		SD	1.545	0.106	0.596	0.181	0.130	–
	Stromfolixyl®	mean	16.38[a]	1.88[a]	6.80[a]	4.42[a]	0.96[a]	–
		SD	2.244	0.339	0.961	0.311	0.133	–
	Calcareous dolomite Control	mean	15.11[a]	1.63[a]	6.59[a]	4.10[a]	0.78[a]	–
		SD	1.532	0.081	0.920	0.227	0.090	–
		mean	16.68[a]	1.90[a]	7.40[a]	4.35[a]	0.88[a]	1.07
		SD	0.843	0.176	0.747	0.476	0.191	0.052

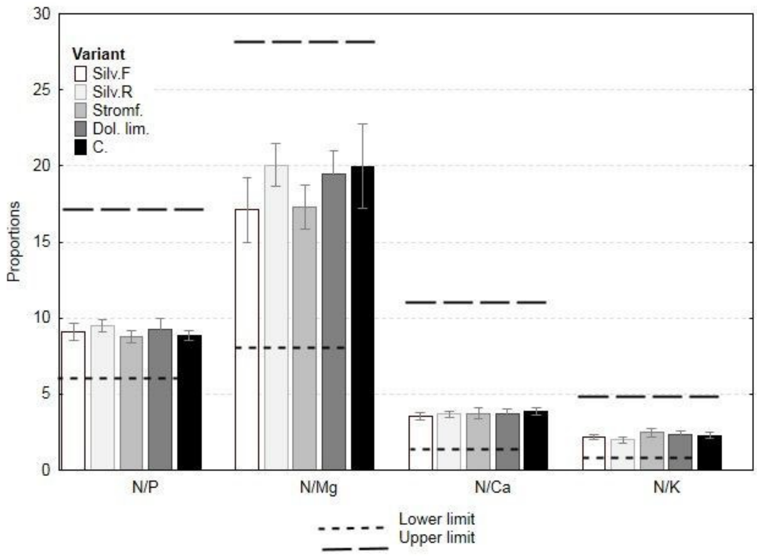
SD = sample standard deviation; K-W test = results of Kruskal-Wallis analysis (overal difference), significant overal diferences at $\alpha = 0,05$ are marked in bold, results of post-hoc multiple comparison by Tukey's test are expressed by letter indexing: mean values in table columns followed by different letter indexes are significantly different from each other at $\alpha = 0,05$. 1 BA – one year before fertilizers application
1 AA – one year after fertilizers application
2 AA – two years after fertilizers application

most nutrients (nitrogen, phosphorus, magnesium, calcium) dropped within the control level. Slightly higher potassium content was found in Silvamix® R (8.1 $g.kg^{-1}$) agent treatment; however, the difference from the control (7.4 $g.kg^{-1}$) was not significant.

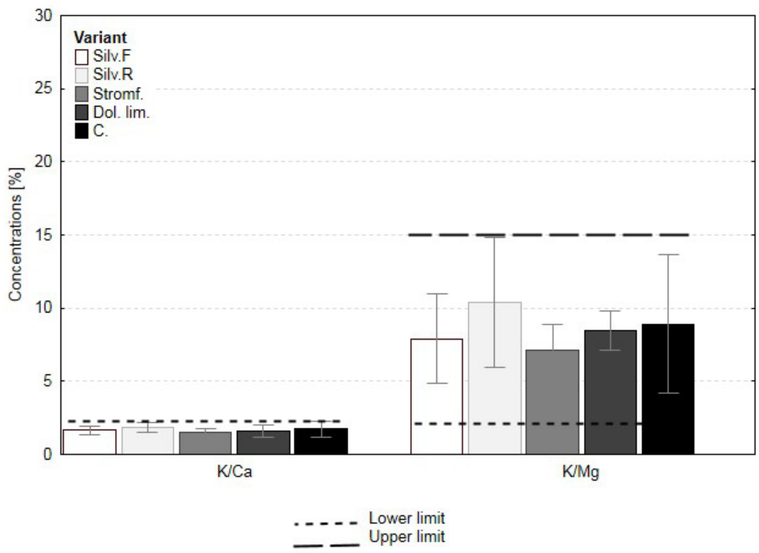
The effect of fertilizers on concentration ratios of selected nutrients

Relative proportions of nitrogen concentration to concentrations of phosphorus, magnesium, calcium and potassium are presented in Fig. 1. There were assessed concentration ratios in the Norway spruce latest needle year dry matter in the period of two years after the fertilizer agent application.

The N and P concentration ratio in the Norway spruce needle dry matter falls in all treatments within optimum range: in compliance with FFCC it is between values from 6 to 17. The N and Mg concentration ratio is also found in the optimum, i.e. for Norway spruce, there are defined values 8 and 28; the latest study (Lomský, 2011) presents the range 18 and 25. The N and Ca concentration ratio in the Norway spruce needle dry matter slightly fluctuated within 3.4–4.0 (lower and upper quartile) and it slightly moved to the low optimum level (2.0). There is evident mild nutrition imbalance; nitrogen uptake is more intense than calcium one. The best ratio was observed at the control (3.9); the nitrogen concentration was not increased artificially. The mutual ratio of N and K concentration in the Norway spruce needle dry matter (2.3) on the control fluctuates within the optimum 1.3–4.9. The lowest ratio was found in the plots with Silvamix® R (2.0) application: its composition shows the highest potassium proportion. Further, foliar potassium concentration was assessed relative to calcium and magnesium concentration; resulting values are presented in Fig. 2: Cape *et al.* (1990) rating scale was used for the assessment. In all treatments the K and Ca concentration ratio decreased below the critical threshold of 2.0. The lowest ratio was found in Stromfolixyl® (1.5) fertilized treatment, the highest was recorded in the treatment with Silvamix® R (1.9) application.



1: *Fertilizers effect on N concentration ratios related to P, Mg, Ca, K in the latest needle-year class of Norway spruce. Situation two years after the application: dashed lines mean the upper and lower limits of balanced nutrition by Fürst (2005). Error bars mean the standard deviation.* Silv.F – Silvamix Forte®, Silv.R – Silvamix® R, Stromf. – Stromfolixyl®, Dol. lim. – Calcareous dolomite, C. – Control.



2: *Fertilizers effect on K concentrations ratios related to Ca, Mg in the latest needle year-class of Norway spruce. Situation two years after the application: dashed lines mean the upper and lower limits of balanced nutrition by Cape et al. (1990). Error bars mean the mean error.* Silv.F – Silvamix Forte®, Silv.R – Silvamix® R, Stromf. – Stromfolixyl®, Dol. lim. – Calcareous dolomite, C. – Control

Within this research area, the K and Mg concentration ratio in the Norway spruce needle dry matter was found in the range of 7.1–9; according to Cape *et al.*, (1990) the values are optimal. The highest average value was found in Silvamix® R (10.3) treatment, the lowest was found in Stromfolixyl® (7.15) application.

The effect of fertilizers on top shoots length

The dynamics of average top shoots length depending on the fertilizers application is presented in Fig. 3. In order to verify comparable growth conditions as a prerequisite for the objective assessment of fertilizer agents' effect, the first measurement was carried out at the end of the first growing season before the fertilizer application itself. At that period, the average length of top shoots in predefined treatments ranged between 4.6 and 4.9 cm. Having applied fertilizers, in the first growing season, in all treatments significant increase in top shoot length values was recorded comparing to the previous year. Higher annual values of top shoot length were detected in all fertilized treatments. Calcareous dolomite and Silvamix® Forte treatments with fertilizers showed conclusive stimulatory effect; slightly positive effect (without statistical significance) was detected in treatments where Silvamix® R and Stromfolixyl® had been applied.

The average length values of top shoots in the second growing season in all treatments reached approx. double value of the previous season. The fertilizers dynamics effect follows the trends of the previous season just partially. A significant positive effect of calcareous dolomite was confirmed; conclusively higher values of the monitored parameter were also found in the treatment with Silvamix® R fertilizer. Silvamix® Forte fertilizer effect was less pronounced that year. The value of annual height increment was slightly higher related to the control; the difference, however, did not reach the statistical significance as well in the case of treatment with Stromfolixyl® fertilizer application.

DISCUSSION

The effect of fertilizers on the concentration of nutrients in the assimilatory organs

Concentration of nutrients in the assimilatory organs at the control indicate the optimal uptake of main nutrients (nitrogen, phosphorus, potassium, magnesium, calcium). Resulting from the opinion of author team, the basic revitalization process in this area consists in spreading line windrows and all-over delivery of organic-mineral material with a high proportion of Csubstances. The initial fertilization effect on the needle nutrients amount was insignificant, even though Vavříček *et al.* (2010) in their study from the identical area of interest indicate, that after fertilizers application, the response in the soil environment was highly significant, and the nutrients increase corresponded to the fertilizers composition. Kuneš (2011) notes that the analysis of the assimilatory organs reflects the nutrients offer in the soil environment better than soil-chemical analyses results.

In the research area of Suchdol, in the first growing season after the fertilizers application, there was observed the slight negative effect of Silvamix® series fertilizers on foliar phosphorus concentration; Stromfolixyl® fertilizer impact was even significant. However, there should be noted, that this nutrient amount did not fall below the optimum quantity on either treatment. This conclusion is also confirmed by Aosaar (2006); he states that the potassium fertilizers increased the foliar potassium content; however, they reduced the phosphorus amount and apart from the exception the magnesium amount as well. The identical trend was observed in the research area of Špičák in the Krušné hory Mts. (Vavříček *et al.*, 2011). The decline in Norway spruce nutrition was also found by Koňasová *et al.* (2012) during their fertilization experiment. However, in that case, there was nitrogen concentration decline caused by applying ground limestone and amphibolites: other nutrients were not affected. The author further states the suboptimal phosphorus concentration in the control as well as in all other treatments, and specifies it as the most limiting nutrient in the area of interest. Phosphorus as a deficient nutrient is also specified in studies by Vavříček *et al.* (2006; 2010) from the Krušné hory Mts. or Pecháček *et al.* (2011) from Hrubý Jeseník area.

The impact of Silvamix® series fertilizers on the Norway spruce nutrition in the Czech Republic mountain locations was also assessed by further authors. In their studies, Vacek *et al.* (2006) and Podrázský *et al.* (2003b) report that optimization of Norway spruce nutrition as well as reduced defoliation and discoloration occurred after the application. The research area of Suchdol showed in the first growing season slight positive effect of calcareous dolomite on the foliar calcium and magnesium concentrations. The same results are also demonstrated by Sikström (2001) who dealt with liming effect on Norway spruce nutrition in Norway. He noted that seedling needles from limed areas showed higher calcium concentrations. Significantly positive liming effect on lime and magnesium content in Norway spruce needles was also observed by Jonard *et al.* (2010), who conducted an experiment in Belgian Ardennes. The author further observed the liming effect in combination with fertilizing (rock phosphate and K_2SO_4): that fact resulted in a significant phosphorus rise.

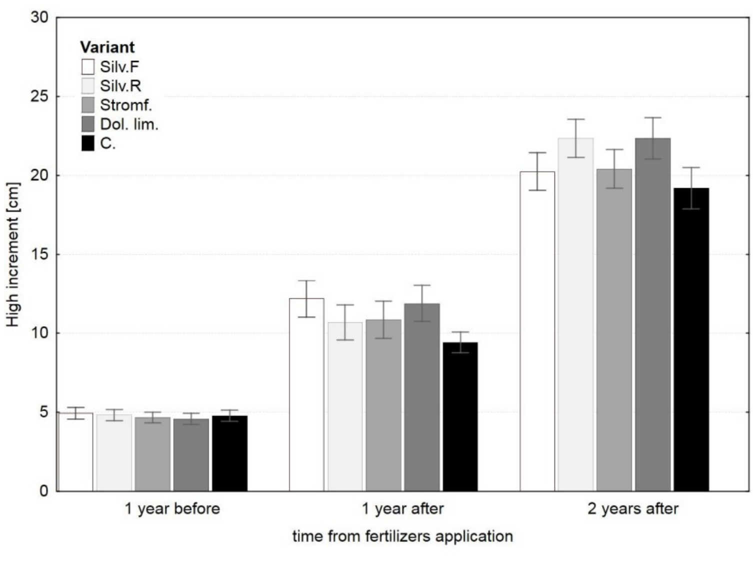
This study results can also be compared with Vavříček *et al.* (2011) investigation: they had carried out experimental investigations using the same fertilizers in Špičák site. The author notes that the fertilizers impact on the Norway spruce nutrition was more significant and the foliar concentration of nutrients supplied were mostly significantly higher comparing to the control. The fertilizer Silvamix® R showed statistically more significant needle potassium saturation. This difference can be caused by the fact that in the past, in Špičák site, friendlier all-over bulldozer technology had been applied (blade with grubbing spikes) and the newly created pseudo-topsoil horizon contains a significantly higher proportion of humic substances (Vavříček *et al.*, 2009). There, soil environment offers higher cation exchange capacity; the sorption potential to bind nutrients being released from fertilizers applied is hypothetically higher.

A more significant fertilizer effect on the nutritional status is also stated in the study by Vacek *et al.* (2009); they applied the fertilizer Silvamix® Mg NPK to the 60-year-old Norway spruce stand in the Šumava. Seven years later, increased magnesium concentrations were observed there. However, it has to be stated that the amount of magnesium supplied corresponded to approximately tenfold dose applied by us. The most striking response to fertilization in terms of chemical composition of needle dry matter is stated by Lomský *et al.* (2006). They applied the powder fertilizer Silvamix® F4 in the same area of interest in a dose comparable to our quantitative dose (300 kg/ha). The author presents a significant increase of phosphorus, magnesium and potassium, which was accompanied by a significantly improved health status of treated individual entities. By the authors' opinion, a more intense response (comparing to our study) may be caused by the fact that older stands showing intensive insufficient nutrition symptoms (yellowing) had been treated: whereas, in our case, plantations with adequate representation of the major nutrients were fertilized. The growth of these plantations was also supported by the stand revitalization through spreading line windrows and further organic material delivery. This hypothesis is confirmed by Remeš *et al.* (2005) study: they tested the fertilizer Silvamix® Mg effect under conditions that are most closely to our study. It was a Norway spruce plantation located within the same area of interest where the same reclamation had been executed. In accordance with our results, the response in terms of the major nutrients uptake was minimal.

Fertilizers effect on the top shoots length

The highest annual increments were measured in the calcareous dolomite treatment. This finding corresponds to the results by Koňasová *et al.* (2012): in the above mentioned work they state the positive limestone effect on the top shoot length; the similar response was also observed with amphibolite application. However, Vavříček *et al.* (2011) present a different conclusion; the calcareous effect on the top shoots length was not noticeable. The same results are also published by Nilsson and Örlander (2003); they presented the forestry experiment results with fertilizers application in Norway. The liming effect on tree growth was insignificant, and in worse cases it was negative. Sikström (2001) came to the same conclusions as well. The liming efficiency effect on the growth of treated individuals does not have to be guaranteed even when combined with fertilizing, which should ensure the nutrition balance. Ingerslev (1999) reports that Norway spruce response after applying both limestone and kieserite and phosphorus did not occur. It should be noted that 60-year-old stand had been treated in that case. In our experience, the fertilization effect both on the nutrition and biomass growth decreases with the increasing vegetation age. However, the positive liming effect may not be guaranteed even in plantations and at considerable higher doses (comparing to our study it is more than tenfold) to monitored individuals as stated by Balcar and Kacálek study (2008). Despite the application of 1 kg of calcareous dolomite in the seedling hole, no increase increment was observed. The positive effect was found only after delivery of 2 kg of powdered amphibolite to each plant.

Furthermore, the results of the study show that fertilizers Silvamix® Forte and Silvamix® R have positive effect on the biomass growth. Remeš *et al.* (2005) in their (above mentioned) work also report that the fertilizer Silvamix® Mg application resulted in significant biomass increase evaluated by the top shoot length. Spot chemical amelioration effects within the pollution site in the Jizerské Mts. were dealt with by Kuneš *et al.* (2008). Silvamix® Forte application could support significantly height increment of Norway spruce and this fact is in accordance with the results of this study. This fertilizer effects were also tested by



3: *The effect of fertilizers on annual height increments within Suchdol site in the Krušné hory Mts. Error bars show the standard error.*
Silv.F – Silvamix Forte®, Silv.R – Silvamix® R, Stromf. – Stromfolixyl®, Dol. lim – Calcareous dolomite, C. – Control.

Bartoš and Kacálek (2013); however, in that case, the height increments of fertilized individuals were comparable with the control entity. Different conclusions, in contrast to our study, may be related to the fact that the experiment had been accomplished at medium altitudes and a silver fir had been a studied woody plant. The authors explain the zero fertilization effect by the attribute that the stand had been established on a former farmland with an excessive nutrient amounts.

CONCLUSION

1. Based on the assessment of the nutrients concentration in the dry needle mater at the control it can be stated that the research area is a sufficiently nutritious site after line windrows spreading. In the course of the experiment, the uptake of monitored nutrients did not fall below the optimum limit; however, a moderate risk may consist in disturbing a nutrition balance. The needle dry mater showed the increased calcium uptake at the expense of potassium.
2. The effect of tested fertilizers within the first two years after the application is as follows:

- Silvamix® Forte fertilizer does not have a significant effect on the nutrition; it does not disturb the nutrition harmony and initiates the increase in the aboveground biomass according to the top shoot length.
- Silvamix® R fertilizer does not have a significant effect on the representation of individual nutrients in the nutrition; in this locality it compensates the risky potassium-calcium ratio towards the optimal values and initiates significantly the increase in length of the top shoot.
- Stromfolixyl® fertilizer did not significantly affect the uptake of monitored nutrients except for phosphorus; its nutrition was affected negatively. Furthermore, potassiumcalcium ratio showed a shift in undesirable direction. This fertilizer did not demonstrate the effect on the biomass increase.
- The treatment with calcareous dolomite did not show a significant effect on the nutrition; there was demonstrated only a slight increase in magnesium and calcium. The treatment using this fertilizer did not affect the nutrition balance; furthermore, there was demonstrated a significant positive effect on the top shoot length.

3. Fertilizers Silvamix® Forte and Silvamix® R can be recommended to encourage the spruce plantation growth in the area of interest. Individuals treated with these fertilizers showed a positive effect on height increment. Furthermore, the fertilizer Silvamix® R initiates the nutritional optimization of potassium-calcium ratio. Calcareous dolomite showed the most favourable effect on the aboveground biomass growth; however, the authors do not recommend its application in this area because of risk due to excessive mineralization of organic matter.

Summary

The aim of this study consisted in verifying the hypothesis whether the application of tableted fertilizers of Silvamix® series and calcareous dolomite is able to effect (1) nutrition, (2) top shoots length of Norway spruce plantations. The experiment was arranged in the Suchdol research area [FTG 6S (*Piceeto-fagetum mesotrophicum*), 880 – 890 m a.s.l., 50°49′67″N; 13°23′86″E]. The site is located in the Krušné hory Mts. where soil dozer technology had been applied in the past. 4 working sectors were arranged within this research area. Individual working sectors were afforested with Norway spruce species. Every selected working sector was divided into five experimental plots: four of them were fertilizers treated, and one was untreated – the control plot. Every single plot was treated with standard tableted fertilizers Silvamix® Forte, Silvamix® R, Stromfolixyl® and sprinkled with finely ground calcareous dolomite.

Needles samplings were always taken at the end of the growing season, i.e. the first year before fertilizers application, the second year after the fertilizers application. Laboratory analyses were carried out by the authorized Laboratory MORAVA s.r.o. resident in Studénka. There were specified contents of nitrogen, phosphorus, calcium, magnesium and potassium. Top shoots length was measured for each individual, which had been fertilizers treated including control plots. Every year, 1.100 Norway spruce individuals were measured having applied this procedure.

The impact of applied fertilizers on the major in nutrients uptake in the Norway spruce needle dry matter was not significant with minor exception. In order to support plantings growth in the area of question, fertilizers Silvamix® Forte and Silvamix® R can be recommended. Having applied the above mentioned fertilizers treatment, the individuals could show positive annual height growth; further, Silvamix® R fertilizer initiated the nutritional optimization of potassium-calcium ratio. Calcareous dolomite had the most favourable effect on the aboveground biomass growth; however, its application is not recommended within this area of interest by authors due to the risks of negative impact on potassium uptake, fast mineralization and nitrogen dynamics within the soil

environment. Stromfolixyl® agent did not show significant impact in the first development stage after the application. This fertilizer did not affect the annual growth height. Further, its impact on the nutrition can be classified as insignificant; fertilized plantations showed significantly lower phosphorus concentrations in needle dry matter.

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