FERTILIZERS EFFECT ON GROWTH AND DEVELOPMENT OF NORWAY SPRUCE TEN YEARS AFTER APPLICATION

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This publication evaluates results of last three years of ten-years lasting trial with slow release fertilizers conducted in the Ore Mountains in the administration unit Horní Blatná. The contribution aims to illustrate the possible effects of slow-release fertilizers on growth and development of young plantations of Norway spruce. The first stage of the trial was established in 2001. Seven different fertilizers were selected to be tested. Five testing blocks were prepared at four locations. Each block contained eight plots. Fertilizers were applied to young seedlings planted at testing blocks. One plot was left without fertilizer as a control. Three selected fertilizers were applied to the trial plots again in 2005 to test the effect in a later stage of the tree development. Quantitative tree features were measured to demonstrate the effect of fertilizers. The best results were observed couple years after the application. The effect of fertilizers applied during the second stage was partially evident as well. However, the overall effect of fertilizers is not considerable when the trees get older. The use of fertilizers could be recommended to shorten the time needed for securing the plantations and support forest regeneration at locations with extreme conditions and at degraded sites.

slow-release fertilizers; fertilization; chemical amelioration; spruce plantations; Ore Mountains

INTRODUCTION

The aim of this contribution is to evaluate last three years of ten years' experiment on growth and development of Norway spruce plantations with use of various types of slow-release fertilizers in the harsh climatic conditions of the Ore Mountains. Forests within mountain regions are clear assets for soil and water. They are also renewable sources of goods and services, employment opportunities, revenues and added value. Therefore, there were selected newly established mountain forest plantations to test ameliorative effects of various fertilizers. The use of fertilizers is generally focused on improvement of nutrient cycles, minimizing the chemical degradation, prevention of further acidification and nutrient leaching due to acid rain; however, the main objective of this experiment is to evaluate and compare the performance of seven different fertilizers from five producers to assess suitability of their use. The nutrients comprised in fertilizers are absorbed by plants and they enrich nutrient cycles directly. The nutrients in fertilizers affect tree growth and development directly what can be easily measured and evaluated. Besides reaching faster height increment it is possible to decrease many negative anthropogenic influences on forest growth and forest soils with a help of fertilizers and liming. Other important role of fertilizers is to provide sustainable forest soil fertility. According to many publications there is fertilization of forest growth practically possible in all age groups (*i.e.* at reforestation, in cultures, in middle age classes and even in older growths). The height increment is the major visible feature of ameliorated forest cultures. This fact should expressively shorten the time period of relatively costly care (mowing, fencing, reforestation losses decrease). Fertilization in higher growth ages follows mainly in volume increment increase (assortment change) or alternatively helps to adjust growth for further planned natural regeneration (Čvančara, 1980). Positive effect of amelioration on improved health state and faster growth dynamic has been proved many times (Assmann, 1968; Remeš, Podrázský, 2002; Burda, 2003; Remeš et al., 2005a), however the results are not definite. Therefore the main use of fertilizer application in forestry still remains on its use at degraded and extreme localities and at areas with high industrial emission loads. According to Nárovec, Jurásek (2000) the fertilizing of forest cultures in areas under pressure of emissions is an integral part of successful forest culture regeneration and forest plantation securing. That happens mainly with use of demanding tree species as beeches, firs and maples. Critical region that fulfills those harsh conditions is the western Ore Mountains area where is needed to restore many degraded localities. Simultaneously, it is necessary to change tree species composition of growths. Natural state of this region is fairly extreme, which

Table 1. Applied fertilizers and their composition

Fertilizer	Producer	Country	Composition (NPK + MgO)	Principle	Tablet (g)
SILVAMIX®	Ecolab Znojmo	CR	11-17-8 + 7.0	ureaform	20
SILVAMIX®FORTE	Ecolab Znojmo	CR	17.5-16-8.5 + 9	ureaform	20
SILVAMIX®MG	Ecolab Znojmo	CR	10-13-6.5 + 16	ureaform	20
FERTIMEL®	Melchemie	NL	20-15-10 + 1	ureaform	15
AGRIFORM®	Scotts	USA	20-10-5 + 0.5	ureaform	10
WOODACE®	Mitsubishi Chem. Co.	JAP	12-6-6 + 2	IBDU	17
AGPRO®	Agpro, Ltd.,	NZ	12-8-6 + 2	ureaform	15

CR – Czech Republic; NL – Netherlands; USA – United States of America; JAP – Japan; NZ – New Zealand; ureaform – urea formaldehyde condensate; IBDU – isobutylen diurea

Table 2. Description of the trial plots

Name	Label	Elevation (m)	Area (ha), slope (%), exposition	Management complex/ forest site type	Soil		Reforestation	
					type	subtype	year	composition (%)
Milíře I	R 15 – 118 L 1b	905	1.62, plateau,SE	73/7K3	Cryptopodzol	modal	2001	NS 50. EB 50
Milíře II	R 15 – 127 A1	840	1.04, slight, SW	53/6K1	Cambisol	mesobasic	2001	NS 70, DgF 30
Smolné pece	R 23 – 301 D1	770–820	0.47, 40, NW	51/6K9	Cryptopodzol	gleyic	2001	NS 70, EB 30
Plavno	R 23 – 410 C1	710–760	0.41, 40, E	51/6S	Ranker	podzolic	2001	NS 75, EB 25

NS – Norway spruce; EB – European beech; DgF – Douglas fir

should be taken into consideration as well (Remeš et al., 2006). The chosen research plots have been observed for ten years and this contribution brings many findings discovered during this period.

METHODS AND MATERIALS

This fertilization research was established in 2001 at the area of Forest District Horní Blatná, the Czech Republic. Methodology was prepared by the Forest Management Institute in Opočno (Nárovec, 2000), which preferred for the arrangement and statistical evaluation the method of random blocks. Five blocks for each species (Norway spruce and European beech) were established. Seven fertilizers from five countries at each block (Table 1) were applied. One block included eight plots at four locations. The characteristics of all locations are shown in Table 2. The natural conditions of western Ore Mountains are characterized by extreme character. There are many degraded areas and habitats affected by emissions that need to be restored because research plots were established there as well.

Seven fertilizers were applied to seven parcels. Only one fertilizer was applied to one plot, and one plot of each block was left without fertilizer as a control variant. There were observed about 300 saplings for each parcel. Fertilizers were applied together with establishment of forest cultures that took place in the spring of 2001. The results of the first stage were evaluated at the beginning of the year 2006 (Remeš at al., 2006).

The second stage of the experiment was initiated in July 2005 with additional application of fertilizers. The fertilization was repeated with use of three types of fertilizers. The fertilizers were applied at the same locations and at the same five blocks as during the first stage. Only three parcels were fertilized again with the use of fertilizers Silvamix®, Silvamix®MG and Silvamix®FORTE. Parcels where these fertilizers were applied during the first stage were split into two parts and additional fertilizer was applied only at one part of each split parcel. All second parts were left without adding more fertilizer. This situation was laid out using pegs in the culture and mapped in the trial scheme. About 150 trees for each added fertilizer were measured at each parcel and about 150 trees without additional fertilization. Approximately 300 trees were again analyzed for all other fertilizers used during the first stage and 300 trees at each control parcel.

Table 3. Average content of biogenic elements for each fertilizer (mg/g of dried sample)

	N	P	K	Ca	Mg
Control plot	17.00	1.36	7.34	2.62	0.84
SILVAMIX®	17.13	1.60	8.27	2.05	0.75
SILVAMIX®FORTE	16.45	1.61	8.13	1.89	0.73
SILVAMIX®MG	16.48	1.20	7.35	2.84	0.93
FERTIMEL®	17.30	1.45	8.12	2.18	0.64
AGRIFORM®	17.00	1.21	7.76	3.04	0.92
WOODACE®	15.40	1.45	8.08	2.79	0.87
AGPRO®	16.00	1.13	7.83	2.31	0.81
Optimum content after Klimo (1990)	18–24	1–3	7–11	0.9–6	0.3–0.8

Remeš, Výlupek (2006) evaluated the results after the first year from adding the fertilizers.

Unfortunately, the beech plantations were severely damaged by browsing due to lack of fence maintenance. Therefore the beech plantations were excluded from the experiment since 2005. Thus three seasons after the additional fertilizer application only the spruce cultures were assessed by Výlupek, Víchová (2010).

Each fertilizer was applied into the soil at the amount of 8–10 g of nitrogen per tree to assure unified measurable base for the experiment.

The quantitative dendrometric data were recorded by collecting annual biometric measurements as total tree height, annual height increment, and root collar diameter.

Mortality was detected at the plots only after the planting out the seedlings. Mortality has not played an important role at plantations during last three years of the experiment. Mortality was observed and there has not been recorded any decrease in number of surviving trees at fertilized and control plots. Therefore tree survival is not a concern and cannot be used as indicator for assessing the overall vitality of trees.

Content of biogenic elements could be used as a vitality indicator of trees. For this purpose there were collected samples of spruce needles at each plot from all locations during winter 2009. The samples were sent to analytical laboratory at Kostelec nad Cernymi Lesy to determine content of biogenic elements.

The analysis of variance was used for basic statistical evaluation of dendrometric data. Each fertilizer was compared and tested at all four locations. Statistical data testing was performed with use of one factor analysis of variance where each plot was assessed separately. Moreover, multiple factor analysis of variance was used for the overall assessment from all locations. The Scheffe's Method of Multiple Comparison was used for detailed testing of distinctness in each variant. All tests were made with use of S-PLUS statistical software at 0.05 level of significance (Remeš et al., 2006).

RESULTS AND DISCUSSION

This contribution sums up the results of last three years of ten years' experiment. Due to large scale of the experiment the average data collected at all locations for each fertilizer are evaluated. This description introduces the effect of various fertilizers. The statistical analysis follows mainly the last three years of the experiment (i.e. 2009, 2010 and 2011).

The content of biogenic elements for each plot received from the analytical laboratory is shown in Table 3. Any of the used fertilizers does not show noticeable better values in all measured elements than other fertilizers. Some fertilizers even show worse results than control plot. Values received from control plot represent average values for all measured elements. Better results for N, P, and K were observed at plots fertilized with SILVAMIX®, SILVAMIX®FORTE and FERTIMEL®. On the other hand, better values for Ca and Mg were measured at plots with SILVAMIX®MG, AGRIFORM® and WOODACE®. All the measured values except for nitrogen are according to Klimo (1990) within optimum limits.

The effects of fertilizers could be clearly observed by annual height increments; therefore this dendrometric feature is discussed more into detail. The annual height increments are shown in Table 4. The statistical significant differences of the height increments between fertilizers were disappearing with following years. During 2009 just two fertilizers (parcels with added fertilizers SILVAMIX® and SILVAMIX®FORTE) showed significantly better performance than fertilizers SILVAMIX®FORTE, SILVAMIX®MG, AGRIFORM®, and SILVAMIX®MG with added fertilizer. Their effect was significantly better than the control variant as well. Only the additionally fertilized variant SILVAMIX® was analyzed as statistically better in the following year 2010 than AGRIFORM®. However, the difference between this fertilizer and control plot was insignificant. There were not any annual height increment differences statistically significant from the last year (2011) of the experiment.

Table 4. Annual height increment (cm) for each fertilizer between 2009 and 2011

		2009	2010	2011
Without fertilizer		52	52	51
SILVAMIX®		55	54	53
SILVAMIX®FORTE		52	54	50
SILVAMIX®MG		51	53	51
FERTIMEL®		55	53	50
AGRIFORM®		53	50	54
WOODACE®		55	52	50
AGPRO®		55	52	51
With added fertilizer	SILVAMIX®	60	58	56
	SILVAMIX®FORTE	58	54	52
	SILVAMIX®MG	52	53	53

Table 5. Total height (cm) for each fertilizer between 2009 and 2011

		2009	2010	2011
Without fertilizer		304	356	407
SILVAMIX®		346	400	453
SILVAMIX®FORTE		319	373	423
SILVAMIX®MG		303	356	408
FERTIMEL®		319	373	422
AGRIFORM®		333	383	437
WOODACE®		309	361	411
AGPRO®		320	372	423
With added fertilizer	SILVAMIX®	361	419	474
	SILVAMIX®FORTE	349	403	455
	SILVAMIX®MG	340	393	446

Root collar diameter is a tree feature expressing the overall vitality of a tree. The measured values are shown in Fig. 1. Statistical analysis has revealed that in 2011 there were several fertilizers proved to be significantly better than others. Especially SILVAMIX®, additionally fertilized SILVAMIX® and SILVAMIX®MG with added fertilizer were significantly better than the control variant. The two best fertilizers (SILVAMIX® and SILVAMIX® with added fertilizer) concerning the root collar diameter, were found significantly better than SILVAMIX®FORTE, SILVAMIX®MG, FERTIMEL®, WOODACE® and AGPRO®. Fertilizers AGRIFORM® and additionally fertilized SILVAMIX®MG showed better performance than SILVAMIX®MG and AGPRO®. SILVAMIX®MG with added fertilizer was even better than SILVAMIX®FORTE and WOODACE®.

The total average heights for each fertilizer are in Table 5. In 2009 fertilizers SILVAMIX®, AGRIFORM® were analyzed together with all variants with added fertilizer (SILVAMIX®, SILVAMIX®MG, SILVAMIX®FORTE) significantly better than the control variant. SILVAMIX® and SILVAMIX®FORTE with added fertilizer had better effect than SILVAMIX®FORTE, SILVAMIX®MG, FERTIMEL®, WOODACE® and AGPRO®. SILVAMIX® with added fertilizer proved to be significantly better than all non-refertilized variants except SILVAMIX®. The results were similar to the following year 2010, even the height increments were not found to be statistically significant. Furthermore, the fertilizer AGRIFORM® was not found significantly better than control variant anymore. The last year of the experiment (2011) did not bring big changes either. Only SILVAMIX® and all variants with added fertilizer were much better than control variant. SILVAMIX®, SILVAMIX® with added fertilizer and SILVAMIX®FORTE with added fertilizer showed better performance than SILVAMIX®FORTE, SILVAMIX®MG, FERTIMEL®, WOODACE® and AGPRO®. The best effect was confirmed with additionally fertilized variant of SILVAMIX®. It was significantly better than all non-refertilized variants except SILVAMIX®.

Variability of measured parameters is shown in Fig. 4. There are shown average values of heights reached by each fertilizer at each plot in 2011. The largest differences for each fertilizer are connected in the graph with two sided arrows. Each fertilizer performed differently at each plot and sometimes even contradictory. Moreover, Fig. 5 shows the largest differences in height measured for each fertilizer in 2011. Fertilizer SILVAMIX®MG reached the highest differences between smallest and greatest values. This greatest difference of 311 cm was measured between plots Plavno and Smolné Pece. This may be caused by some negative influences at the plot Plavno or the mentioned fertilizer is not suitable for universal use in diverse conditions. Very low values were also measured at the plot Plavno for fertilizer WOODACE®. Therefore it is possible that the locality features might influence the results of fertilizers. Parcels of both affected fertilizers lie next to each other at this plot. Unfortunately, this assumption cannot be verified by the evidence (e.g. soil analysis). Soil samples have not been analyzed due to high financial costs and low budget of the project. On the other hand, fertilizer SILVAMIX® reached similar results at all locations and it was found as the most effective fertilizer at the overall evaluation if we do not consider the variants with added fertilizers. It seems that SILVAMIX® could be considered as the most universal fertilizer among those tested. Differences measured at all locations for other fertilizers showed similar values as the control variant. The highest height values were measured at the plot Smolné Pece. This plot could be considered as the most optimal for the growth of Norway spruce. The smallest values were recorded at plots Milíře 1A and Milíře 1B. These plots are located at the least suitable conditions among the tested plots. It is important to state that all fertilized variants showed better results than control plot.

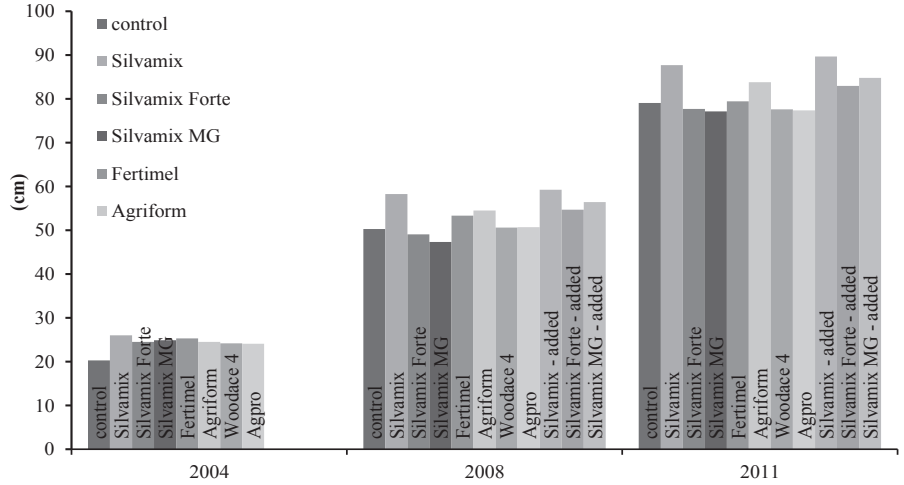

Fig. 1. Average root collar diameter (cm) for each fertilizer

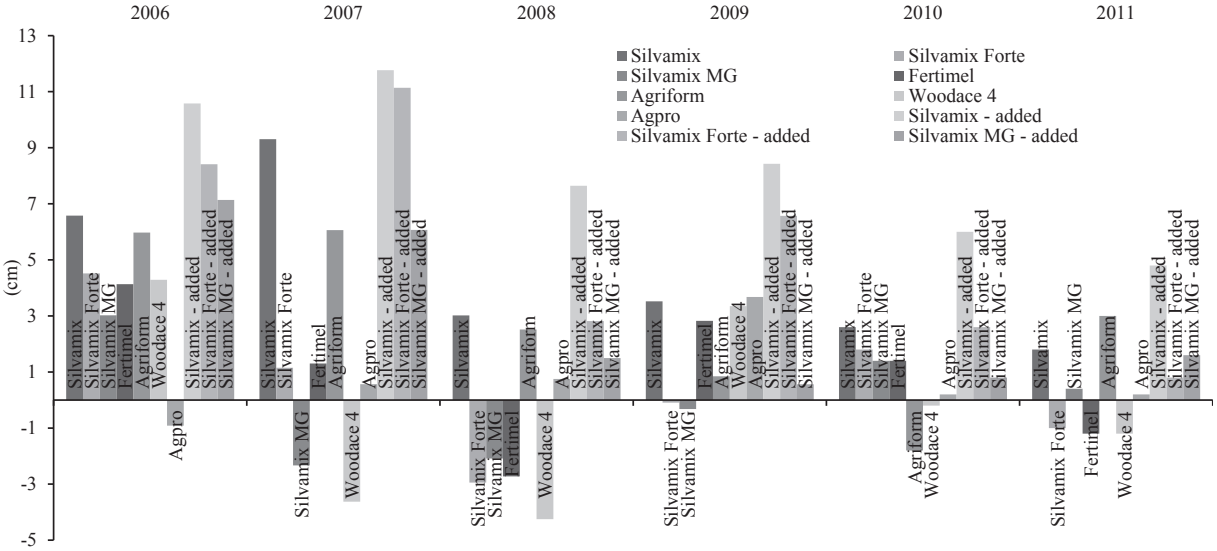

Fig. 2. Average height increment deviations (cm) for each fertilizer in years 2006–2011

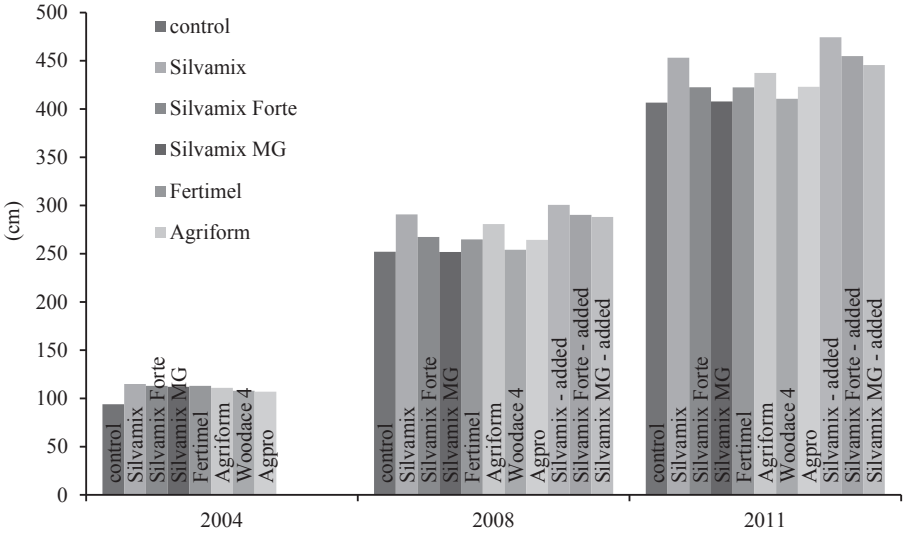

Fig. 3. Average heights (cm) for each fertilizer

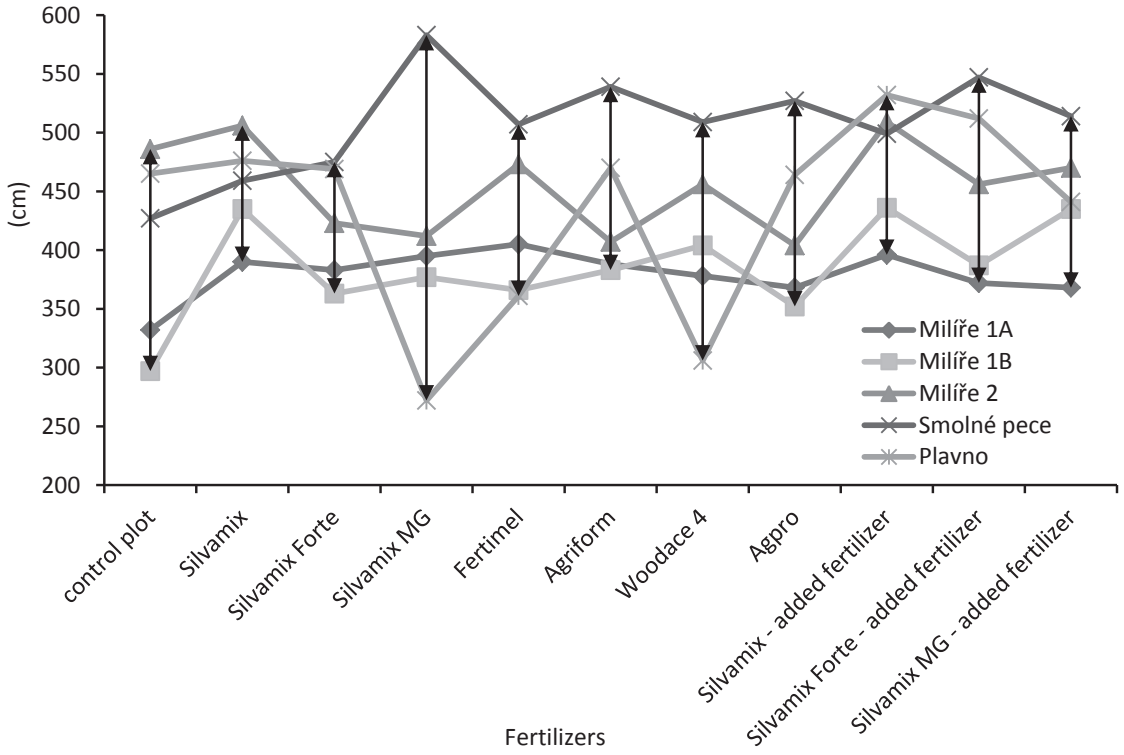

Fig. 4. Average values of heights reached by each fertilizer at each plot in 2011. The two sided arrows connect largest differences measured for each fertilizer

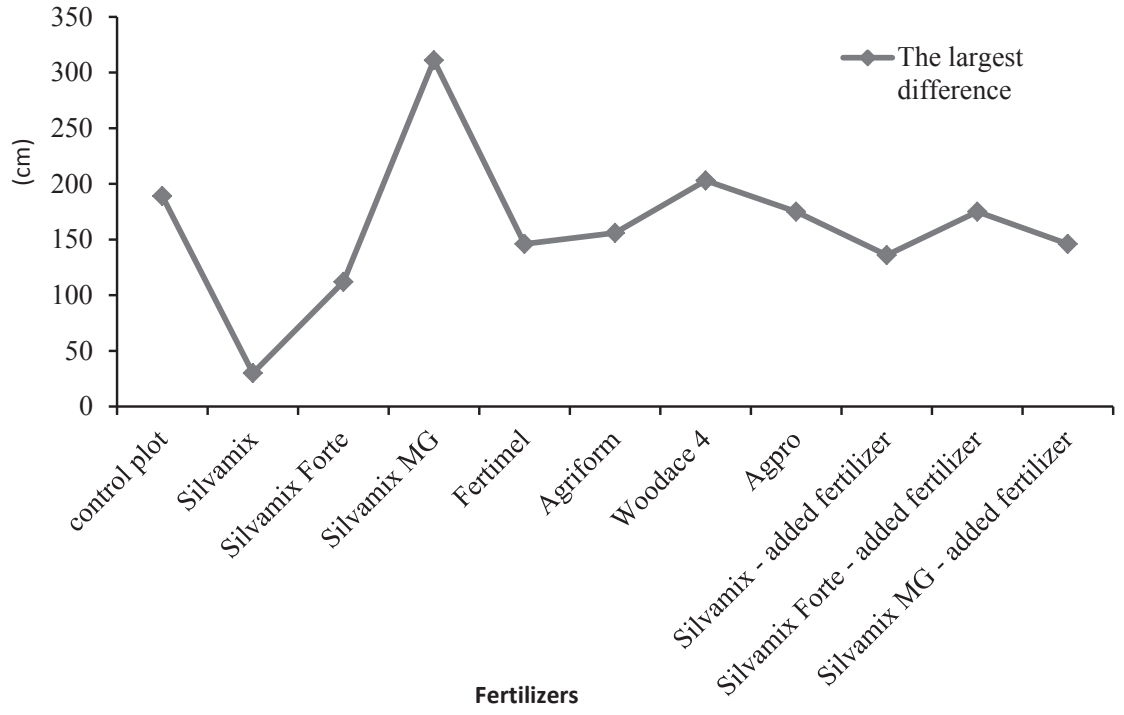

Fig. 5. The largest differences in height measured for each fertilizer in 2011

It can be said that used fertilizers helped young trees to grow faster in juvenile stage to escape competition of weeds and browsing of game animals under given conditions. This faster growth was observed even in secured culture. These findings could be used in case of deciding whether the faster growth of young seedlings is required.

Several authors have given evidence of positive effect of fertilizers that were used in forestry. Remeš et al. (2004) tested the effects of SILVAMIX® fertilizers on growth of fir and spruce plantations in mountain areas. The results of fertilizers applied in Ždárské Vrchy to plantations of Giant fir were assessed very positively. The difference after seven years between fertilized and control variant was more than one meter. Other experimental plot located at Jizerské Mountains showed positive results at plantations of Norway spruce. The trees at fertilized variants showed the largest height increments. Their experiment also detected that in some cases the extreme conditions at the chosen locality can lead to time delay between fertilizer application and the maximum effect of fertilizers. The delay in nutrient release was not observed at Horní Blatná experiment and the difference of one meter has not been reached between the control plot and any fertilized variant. The largest difference at the end of experiment reached 50 cm for not additionally fertilized variant of SILVAMIX® and 70 cm for the variant with added fertilizer SILVAMIX®. Remeš et al. (2005b) also tested SILVAMIX® and Cererit fertilizers at degraded sites after bulldozer preparation in the Ore Mountains at locality Boleboř. The positive effects were assessed mainly at plots where SILVAMIX® fertilizer was applied. They proved that fertilization can be effectively used to support young plantations at degraded sites. One of the findings at Boleboř was that effect of fertilizers was slowed down during a dry year of 2003 because of slower release of nutrients. The annual amount of precipitation from the year 2008 was recorded 700–800 mm therefore the possible influence of precipitation on nutrient release cannot be verified in this case. Nárovec et al. (1991) tested the effects of fertilizers on reclaimed plots after sand excavation. Their trial plots were located at elevations 250–300 m a.s.l.. They assessed the effects of adding magnesium and nitrogen fertilizers to cultures of *Pinus sylvestris*. The effects were visible only up to three years after the fertilizer application. The statistically significant effects of fertilizers at Horní Blatná were recorded even the fifth year after the application. According to Nárovec, Jurásek (2000) it cannot be guaranteed that fertilizer showing promising results at one location would perform the same way somewhere else and vice versa. The variability of measured results at different locations of the Horní Blatná forest district this statement confirms. However, it would be needed to add the soil analysis in the experiment to confirm or deny the effect of soil properties on different results (e.g. plots Milíře 2 and Plavno). It could be recommended to focus further research on how the local soil properties affect release of fertilizers.

CONCLUSION

The main aim of this contribution was to evaluate the effect of fertilizers on growth of Norway spruce ten years after the application. Seven different fertilizers were tested, and this work evaluated the suitability of the use of each fertilizer under the conditions of the Ore Mountains. The year 2011 was the tenth year after the trial establishment. At the end of the experiment the fertilizer's effect was completely diminished. Fig. 2 shows annual increment deviations where the control variant is taken as a base. The each presented value means a difference between each fertilizer and control variant. It is still possible to observe some fertilizer effect in 2006 at additionally fertilized parcels. However, it is obvious that even the additional fertilizers were exhausted by the end of a decade. The trees fertilized with the most effective fertilizers profited in heights even in 2011 because of height margin gained during couple of years after the fertilizers application (Fig. 3). The largest heights were measured at the variant with additional fertilization of SILVAMIX®. This fertilizer showed 67 cm difference compared to control variant, which represents 116% of the control variant height. Even trees growing at the parcel where the slowest performing fertilizer was applied (SILVAMIX®MG) proved to be 15 cm higher than the control plot at the end of experiment. It is visible in Fig. 1 and Fig. 3 that the best performing fertilizers ended up in 2011 fertilizers SILVAMIX®, AGRIFORM® and all variants with additionally added fertilizers. On the other hand, the SILVAMIX®MG and WOODACE® have shown the lowest possible effect among fertilizers in terms of total heights and they provided smaller root collar diameter than variant without fertilizer. On top of that even variants fertilized with SILVAMIX®FORTE, FERTIMEL® and AGPRO® have not proved to assure larger root collar diameter after ten years at the end of the experiment.

The acquired results proved that the use of fertilizers could shorten the time needed for securing the forest cultures by the greater height increment. The differences between some fertilized parcels and non-fertilized one were significant even ten years after the application. The additional use of fertilizer at the age of five years demonstrated acceleration of tree growth. The fertilizers seemed to be exhausted at the age of ten years and the differences between heights were still evident. It is needed to mention that the height increment would be desirable mainly at the younger stage of trees to overgrow the competitive weeds and escape the browsing of game animals faster. The secur-

ing of forest cultures might be more demanding at the extreme locations and at the areas severely affected by industrial emissions. The results proved that the use of fertilizers could be recommended. Silvicultural technique would serve as a suitable complement of forest regeneration at these locations. However it is important to choose the correct timing and dose of applied fertilizer to gain the best results with the possible lowest financial inputs into the production. Slow-release fertilizers commence releasing the nutrients right after the application and the best performance could last about four years. The attention might be paid to the fact whether the trees are able to absorb all the applied fertilizer right after being planted out or whether it is better to wait till the next season after planting out the seedlings to avoid possible leaching of nutrients away from the soil.

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Vliv hnojení na růst a vývoj smrku ztepilého v juvenilním stadiu deset let po aplikaci

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Tato publikace shrnuje výsledky posledních tří let desetiletého pokusu s pomalu rozpustnými hnojivy, který byl založen v Krušných horách v oblasti lesní správy Horní Blatná. Příspěvek se zaměřuje na prokázání možných účinků pomalu rozpustných hnojiv na růst a vývoj mladých výsadeb smrku ztepilého. První etapa pokusu byla založena v roce 2001. K pokusu bylo vybráno sedm různých hnojiv. Bylo připraveno pět bloků na čtyřech lokalitách. Každý blok obsahoval osm ploch. Na plochách byla aplikovaná hnojiva k vysazeným sazenicím. Jedna plocha byla ponechána bez hnojiv jako kontrola. Tři vybraná hnojiva byla v roce 2005 na plochy aplikovaná znovu pro testování efektu na odrostlejších sazenicích. K demonstraci efektu hnojiv byly zaznamenávány kvantitativní znaky stromů. Nejlepší výsledky byly pozorovány několik let po aplikaci hnojiv. Ve druhé fázi byl efekt přihnojení patrný jen částečně. Avšak celkový vliv hnojiv nebyl významný v odrostlých kulturách. Použití hnojiv může být doporučeno pro zkrácení doby potřebné k zajištění kultury a k podpoře obnovy lesa na plochách s extrémními podmínkami a na degradovaných stanovištích.

pomalu rozpustná hnojiva; hnojení; chemická meliorace; smrkové výsadby; Krušné hory

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