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Intensive initial care of silver fir using improving compounds: A way to support diverse forests?

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Abstract: In some cases, it is difficult to promote climax tree species in the forest stand composition. In the Czech Republic, silver fir (*Abies alba* Mill.) is a typical example. This study offers an evaluation of the use of two improving compounds for tree plantations in the initial stage of growth in Central Bohemia. In the experiment, we measured the initial growth performance of a young fir plantation treated with a brassinolide compound (concentration 1 : 100 and 1 : 200) and Bio-Algeen® prior to planting and compared it with control treatment: we assessed height, root collar diameter, vitality and mortality rate during the period 2014–2019. Cumulative mortality rate of the plantation reached 25% at the end of the monitoring period, without any significant differences between variants. Height increment of the variant treated with Bio-Algeen® was significantly ($P < 0.05$) lower than the growth of brassinolide-treated variants, all treated variants were comparable with the control variant. The plantation underwent a drought-stress period in 2014 and 2015, which resulted in worsened vitality and colour across variants. As a result of the simple economic analysis, the most expensive inputs are planting stock and labour, therefore the price and application of additional substances should not affect decision-making.

Keywords: *Abies alba*; brassinolide; Bio-Algeen®; forest regeneration; silviculture

Forests are an essential part of the terrestrial environment. In some parts of the world, previous woodland areas are devastated or already non-existent due to human activity and it has a drastic impact on the well-being of humans (Hobley 2005; Vacek et al. 2021b). Where diverse forests are present, also the support of biodiversity is very high in comparison with non-forested areas like agricultural land (Grainger 2013).

In Central Europe, some forests have been drastically changed in the past in terms of structure and tree species composition (Holubík et al. 2014; Cukor et al. 2020). Silver fir (*Abies alba* Mill.) was one of the most impacted climax species, which was an abundant species on the area of today's Czech Republic, as it expanded naturally across Central Europe in response to climatic change after the last glacial period, before the beginning of extensive

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Neolithic human activities (Tinner, Lotter 2006). But through history, other species, particularly Norway spruce (*Picea abies* L. Karst.), were preferred at the expense of silver fir (Vacek et al. 2015; Podrázský et al. 2018).

Silver fir is the main canopy tree species especially in the 4th–6th forest vegetation zone (Žárník, Holuša 2005; Poleno et al. 2009). The most favourable conditions for silver fir are northern slopes with high air humidity (Dinca et al. 2022). In these conditions it forms mixed forests together with European beech (*Fagus sylvatica* L.) and Norway spruce (the so-called Hercynian mixture) (Musil 2003). The uneven-aged mixed stands with a complicated internal structure are typical (Hofmeister et al. 2008; Slanař et al. 2017; Štefančík et al. 2021; Dinca et al. 2022). In the other forest vegetation zones, fir usually occurs only as a mixed or interspersed tree species and it usually has reduced vitality. It maintains its share there mainly thanks to its ability to survive in the shade for a long time, possibly thanks to its ability to grow on alternately moist and waterlogged soils, where it has an irreplaceable function in terms of the stability of forest stand production (Korpeľ 1989; Dobrowolska et al. 2017; Mikulenka et al. 2020). Silver fir is also an important tree species in terms of wood production (Štefančík 2019; Mikulenka et al. 2020; Prokůpková et al. 2021). Stands of silver fir showed lower sensitivity to different climatic factors than Norway spruce stands in recent studies (van der Maaten-Theunissen et al. 2013; Dobrowolska et al. 2017; Vitali et al. 2017). In provenance trials, Czech populations showed better growth in comparison with foreign, particularly Italian provenances (Fulín et al. 2023).

Since the mid-19th century, the decline and even mortality of silver fir have been recorded. The dieback reached the peak in the second half of the 20th century. The air pollution is considered as the main but not the only reason for fir dieback. Nowadays, a substantial improvement in the health status is observed across Europe (Elling et al. 2009). Unsuitable clear-cutting management, air pollution and outbreaks of *Dreyfusia* caused a rapid decline of this species (Mrkva 1994; Boettger et al. 2014; Dobrowolska 2017; Novák et al. 2019; Mikulenka et al. 2020). In recent years, the decline of silver fir has also been attributed to climate change (Hanewinkel et al. 2013; Boettger et al. 2014; Konôpková et al. 2018). In particular, the repeated summer heatwaves and long-term drought periods had a significant impact on the health status of silver fir (Büntgen et al. 2014; Gazol et al. 2015; Konôpková et al. 2018). Silver fir is often preferred by ungulates for browsing that is a substantial obstacle to natural or artificial regeneration (Häsler, Senn 2012).

Ministry of Agriculture of the Czech Republic (Ministry of Agriculture 2020) estimates the original proportion of silver fir in the forest cover before the intensive influence of humans to 19.8%, but nowadays its representation is only around 1.2% in the Czech Republic. Meanwhile, the outlined recommended representation by Ministry of Agriculture (2020) in the future is 4.4%. Generally, silver fir is considered as an ameliorative (or also "site improving") and stand stabilising species on many sites, similarly like European beech (Podrázský, Remeš 2010; Gallo et al. 2018). According to the Czech legislation (Regulation No. 298/2018), silver fir is included among the tree species with site improving and stand stabilizing functions. In the above-mentioned regulation the minimal share of tree species is demanded through forest restoration. Its ameliorating effects were confirmed by recent studies (Podrázský et al. 2018). It is also important that the roots of silver fir reach much deeper and are able to gain sufficient nutrients from the whole soil profile (Novotný 2023). Other studies showed, however, only a minor ameliorating effect of silver fir in comparison with Norway spruce. Higher content of total N, P, Ca and slightly accelerated litter decomposition were recorded, pedochemical characteristics were comparable (Třeštík, Podrázský 2017).

Silver fir is often preferred for forest reforestation, in the efforts for diversification and increasing the stability of forests (Pach, Podlaski 2015). Fir is considered as a shade-tolerant climax tree species which can survive the under the crown canopy for decades, but insolation is needed to reach a substantial height increment (Polách, Špulák 2022). On the other hand, the environmental conditions on large-scale salvage-logged clear-cuts are adverse (Poleno et al. 2009; Vaněk, Mauer 2014). The planting of fir in the conditions of full insolation usually does not show a negative influence on the height growth, however, the conditions of the clear-cut area initially contribute to increased mortality and frost injury, and worsened vitality of the young plants (Vaněk, Mauer 2014). Therefore, silver fir is a desirable tree species for

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use in stand reconstructions as underplanting under dying Norway spruce stands (Simon et al. 2006; Vencurik et al. 2015). The appropriate way may be to plant silver fir in the mixture with rowan tree (*Sorbus aucuparia*) which offers the desired protective shelter but does not substantially inhibit the growth of fir (Kacálek et al. 2023).

A possible solution is the two-phase forest regeneration, which, however, takes a longer period of time, in the order of decades to reach the climax state (Šafránek et al. 2018; Polách, Špulák 2022). Is it possible to support climax tree species in a way so that at least in some parts of large areas it is possible to count on their existence and production already in the first stages of forest regeneration?

The aim of this study was to find differences between the plantation treated with a brassinolide compound and Bio-Algeen® and the control variant to decide whether these substances could be useful for the initial intensive care of a target tree species – silver fir. The specific objectives were to determine differences between variants with regard to (*i*) mortality rate, (*ii*) height and root collar diameter, (*iii*) height and diameter increment, (*iv*) vitality and (*v*) economic costs. It was hypothesized that the brassinolide compound (BRs)- and Bio-Algeen®-treated part of the plantation would show increased growth and vitality and decreased mortality.

MATERIAL AND METHODS

Study site

The experimental plot was situated at the Truba Research Station close to Kostelec nad Černými lesy, Czech Republic (GPS: 50°0.36'N, 14°50.25'E, altitude 365 m a.s.l.). The surface is flat, the soil is sandy loam, and the area is exposed to direct sunlight for most of the day. The stand conditions represent afforestation of abandoned agricultural land. The area was protected by a deer-exclosure fence.

Considering that the positive effect of both used improving substances should manifest more clearly in the adverse conditions, we intentionally chose the locality for establishing an experimental plantation with such stand conditions that do not represent the optimal stand demands of silver fir.

An automatic meteorological station is monitoring weather conditions within the experimental plantation (data logger type: LEC 3010, Libor Daneš Company, Czech Republic; GPS: 50°0.382'N, 14°50.236'E; elevation: 365 m a.s.l., 3rd forest vegetation zone). Long-term average annual temperature is 7.9 °C and annual rainfall around 670 mm (1961–2021; Ondřejov meteorological station, 490 m a.s.l.). The comparison with basic climatic conditions measured on the research plot in 2014–2019 is shown in Table 1. Precipitation throughout the year was measured by a standard non-heated tipping bucket rain gauge with the circular surface of 500 cm^2, i.e. diameter ≈ 25.3 cm. Precipitation in the vegetation period was calculated as the sum of daily precipitation in the period from April to September. Analysis of soils on this research site was done in detail in a previous study (Gallo et al. 2020).

Planting and planting stock

Five-year-old bare-rooted planting stock of silver fir was used. Planting stock was grown in the Burda Forest Nursery, Milevsko, Southern Bohemia, according to the 2 + 3 cultivation formula, i.e. seedlings were grown on a seedbed for two years, then they were transplanted to a nursery bed and grown there for another three years. The experimental plantation was established at 1 m × 1 m spacing in April 2014 and the rows of the control and treated seedlings alternated. The unusually dense spacing was used in order to restrict the used area to achieve as homogeneous stand conditions as possible.

In total, 880 transplants were planted: 352 plants treated with Bio-Algeen®, 176 BRs-treated (concentration 1 : 100), 176 BRs-treated (concentration 1 : 200) and 176 plants in the control variant. Application of Bio-Algeen and BRs was done twice, on May 20, 2014 and on June 9, 2015. Control trees were without any treatment. Weed control was

Table 1. Climatic conditions on the experimental plot measured by automatic station

Year	Average annual temperature	Temperature in vegetation period	Sum of annual precipitation	Precipitation in vegetation period
	(°C)		(mm)	
2014	10.4	15.5	563	379
2015	10.6	16.2	451	211
2016	9.3	15.4	525	301
2017	9.6	15.5	533	340
2018	10.9	18.2	389	219
2019	10.2	15.9	528	315
Mean	10.2	16.1	498	294

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done by trampling during annual measurements and engine-trimmer was used, as required, at least once a year. The monocotyledonous grass (e.g. the genera *Calamagrostis*, *Festuca*, *Arrhenatherum*, *Alopecurus*, *Holcus*) prevailed, there were also dicotyledonous genera (e.g. *Hypericum*, *Acetosella*, *Urtica*). Initial measurements of height and root collar diameter were performed in spring 2014 (initial values). Periodic measurements of height and root collar as well as records of mortality rates were taken annually in autumn in 2014–2019 (after the vegetation period). Mortality rates were calculated as the percentage of dead transplants related to the initial numbers of plants. Vitality and colour of trees were assessed visually according to a vitality scale (Kuneš et al. 2011; Gallo et al. 2017).

Treatment

Two improving substances were used to enhance initial vitality of the plantation – a brassinolide compound (BRs) and Bio-Algeen®. The brassinolide compound is a part of brassinosteroids group (Nováková et al. 2014, 2015; Gallo et al. 2017) and it was patented in 2003 (Kohout et al. 2003). Bio-Algeen® is a preparation based on the hydrolyzate of the brown alga *Ascophyllum nodosum* produced in the form of granules, spray or wet root coating material (Hanzal et al. 2015).

Brassinolide. The norm was 20 mL of the solution per tree. In the original preparation, the concentration of brassinolide was 0.4 mg·L^{-1}. This was diluted at 1 : 100 or 1 : 200, i.e. in 1 : 100 dilution there was 0.004 mg·L^{-1} and in 1 : 200 dilution there was 0.002 mg·L^{-1}. Divided by 50, the dose in mg of brassinolide per one seedling comes out.

Bio-Algeen®. Regarding the application, it was sprinkled with a dropper, 1 L per seedling, which was 352 litres per plantation. It was done immediately after planting.

Economic calculation

One of the important aspects that is monitored when assessing the effectiveness of new methods is the financial performance and evaluation of economic parameters. The table below shows the financial values of the primary inputs for growing transplants that were used for the research. Basic costs comprise transport costs, planting stock, outplanting labour, fencing and subsequent weeding and protection. Extra costs comprise particularly the treatments with different substances. An overview of costs entering the simple economic analysis is in Table 2.

Table 2. Overview of costs entering simple economic analysis

Item / Activity	EUR·unit^{-1}	per 1 ha	EUR·ha^{-1}
Basic costs			
1 plant (transplant)	0.5	4 444 (spacing 1.5 × 1.5)	2 222
Labour costs planting 1 tree	0.5	–	2 222
Transport	0.4 (EUR·km^{-1})	2 × 100 km	80
Weeding	300	–	300
Fence	–	–	400
Extra costs			
BRs 1 : 100	50	–	50
BRs 1 : 200	50	–	25
Bioalgeen®	70	–	70
BRs preparation and app.	10	–	10
Bioalgeen® preparation and app.	20	–	20

BR – brassinolide

The costs related to the purchase of planting stock, outplanting labour, transport, weeding and protection were compared. The common spacing (rather sparser in comparison with the experimental plantation) was used in the model forest stand for calculation. The transport costs are, of course, strongly dependent on the distance. The price of planting stock was derived from the current prices in the Czech Republic (Burda 2019), the exchange rate of EUR to CZK was 1 : 26. For the purposes of the analysis, we considered the labour costs of outplanting of one transplant to be EUR 0.5. The fencing costs were estimated to be 4 000 EUR·km^{-1}, based on our previous experience. In this case, 500 m to fence 1 ha (400 m of a perfect square plus extra 100 m for irregularities in the real shape) was considered.

Transport costs are calculated as the costs of vehicle with trailer per km, which were approximated to 0.4 EUR·km^{-1}. In our model case, the transport from Milevsko nursery to Truba Research Station was calculated (100 km). In the case of purchasing a larger number of trees, transport is usually free.

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Application of BRs was done to 352 individuals, spreading duration and movement from tree to tree were approximately 10 s per tree. 352 plants therefore mean 3 520 s + considering the dilution and preparatory work around, resulting in app. 2 h. The price could not be established as it is an experimental product, but considering the amount, it can be almost negligible.

Application time of Bio-Algeen® was also 2 h – delivery and sprinkling of the seedling are a matter of 2 s, but everything around (10 s) the total time is 2 h. The 10-litre canister cost was ca 100 EUR, 1 seedling was diluted = 1 L containing 2.5 mL of Bio-Algeen®. Total cost of Bio-Algeen® can be estimated to 10 EUR.

Control. The control variant had an obvious advantage because neither cost of additive chemicals nor additional labour of the application of those chemicals was required.

Data analysis

The analysed data included the trees which had survived until autumn 2019. Data relating to the trees that died by autumn 2015 were retrospectively excluded. Some severely damaged living trees (especially those injured by a brush cutter during weed cutting) were also excluded.

Data were digitized and adjusted in MS Excel (Version 365, 2022). Statistical analyses were done in R software (Version 4.0.2, 2020). Annual mortality rate was assessed by test for quantities corresponding to binomial distribution using a predefined script [Linda (2020) according to Agresti et al. (2008)]. In height and root collar diameter increments, the Shapiro-Wilk test was used to test normality of data. Subsequently (as the data showed other than normal distribution), the Kruskal-Wallis test with multiple comparisons was used to find possible significant differences between the variants. Then, the Kruskal-Wallis multiple comparison test from the package 'pgirmess' was used to test particular differences. The principal component analysis (PCA) was performed in Canoco 5 program (Šmilauer, Lepš 2014) to evaluate the relationship between seedling parameters, climate factors and treatment variants. Data were log-transformed and standardized before analysis. The results of the multidimensional PCA analysis were visualized in the form of ordination diagram.

For vitality assessment, a scale for rapid visual assessment of the health status was used (Gallo et al. 2017): A – excellent; B – good; C – somewhat worsened; D – significantly worsened; E – dry. Dead trees were also excluded from the analysis of vitality and colour. For evaluation of needle colour, a three-degree scale was used (1 – green, 2 – green-yellow, 3 – yellow). Vitality and colour assessment was done only in the years 2014 and 2015. In the next years these parameters were not recorded because the majority of trees overcame the postplanting shock (or died) and no extensive colour and vitality differences were observed.

RESULTS

Mortality rate. No statistical differences in annual mortality between variants were observed. Notably increased annual mortality was registered in 2015 for all variants. Otherwise, values of annual mortality were generally low, in BRs 1 : 100 and control variant they were zero in the last three monitored seasons (Table 3). Although the climatic conditions in 2018 were similar to those in 2015, almost no annual mortality was registered. In the fifth season after planting (2018), the root systems of the trees were well developed. Therefore, the survival rate in the extreme drought period was very high, contrarily to the second season (2015).

Cumulative mortality rate of the plantation reached 25% at the end of the monitoring period in 2019. Mortality according to each treatment is shown in Figure 1. The lowest cumulative mortality was registered in control treatment (20.5%), while the highest was in BRs 1 : 100 treatment (29.5%). *P*-values were not statistically significant.

Height and root collar diameter. Mean height development of fir individuals differentiated according to variants is shown in Figure 2. It was similar in all treatments with Bio-Algeen® show-

Table 3. Annual mortality rate (%) of different treatments of silver fir plantation in the period 2014–2019 on the research plot Truba

Treatment	Year					
	2014	2015	2016	2017	2018	2019
Bio-Algeen®	2.27^{a}	21.22^{a}	1.11^{a}	0.37^{a}	0.00^{a}	0.37^{a}
BRs 1 : 100	0.00^{a}	26.70^{a}	3.10^{a}	0.00^{a}	0.00^{a}	0.00^{a}
BRs 1 : 200	0.57^{a}	24.00^{a}	1.50^{a}	0.00^{a}	0.76^{a}	0.00^{a}
Control	0.57^{a}	18.86^{a}	1.41^{a}	0.00^{a}	0.00^{a}	0.00^{a}

Different letters indicate significant differences; BRs – brassinolide

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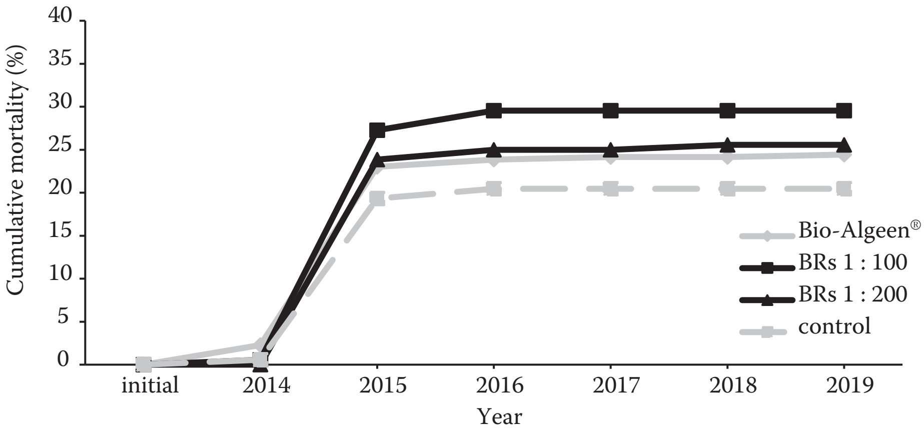

Figure 1. Cumulative mortality (%) of different treatments of silver fir plantation in the period 2014–2019 on the research plot Truba

BRs – brassinolide

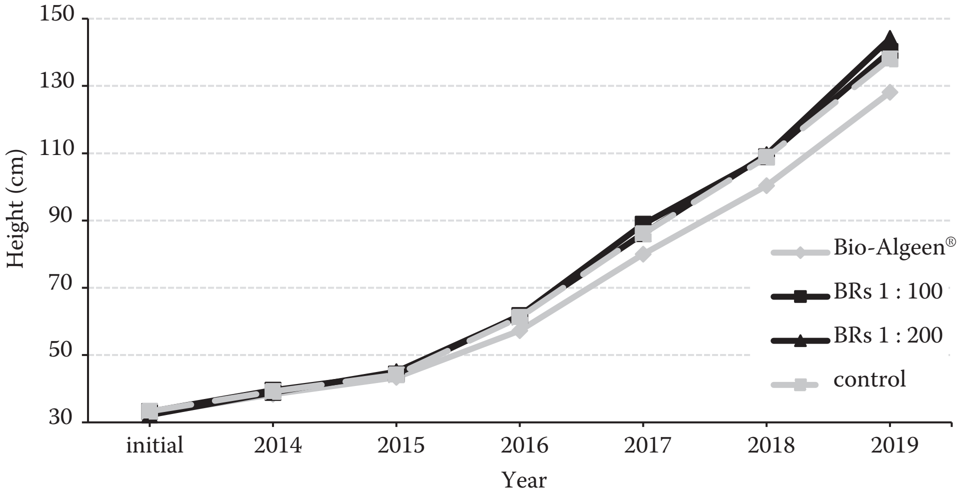

Figure 2. Mean height (cm) development of different treatments of silver fir plantation in the period 2014–2019 on the research plot Truba

BRs – brassinolide

ing the lowest values (128.1 cm) at the end of the monitoring period. The highest values were shown by BRs 1 : 200 treatment (144.1 cm). BRs 1 : 100 and control treatment showed 140.3 cm and 138.1 cm, respectively.

Mean root collar diameter development is shown in Figure 3. The yearly values were similar in all treatments. In absolute numbers, control treatment showed the lowest root collar diameter (28.7 mm) at the end of the monitoring period. BRs

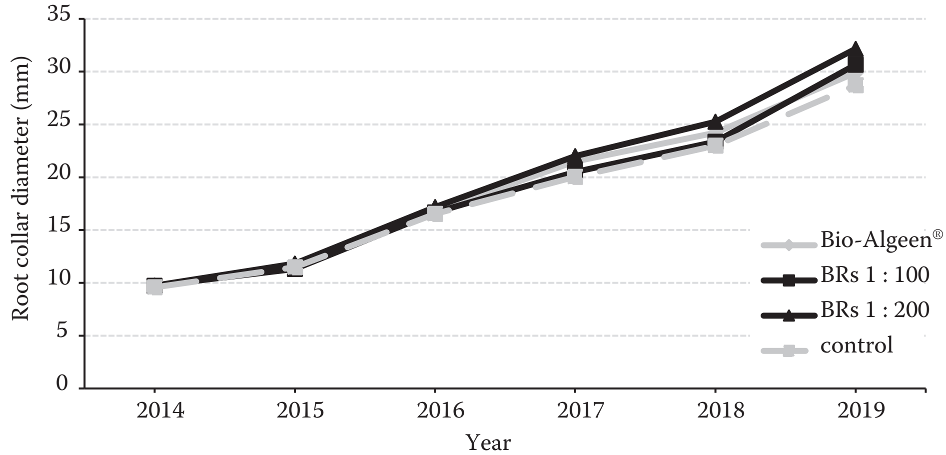

Figure 3. Mean root collar diameter (cm) development of different treatments of silver fir plantation in the period 2014–2019 on the research plot Truba

BRs – brassinolide

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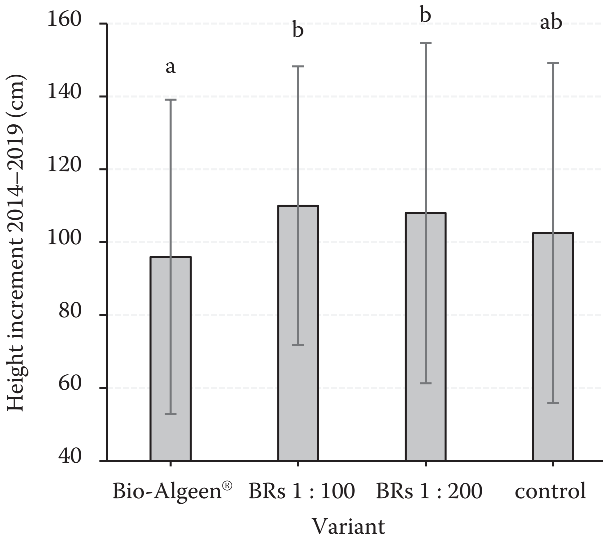

Figure 4. Median height increment (cm) of different treatments of silver fir plantation in the period 2014–2019 on the research plot Truba

Different letters indicate significant differences according to Kruskal-Wallis multiple comparisons test; error bars – standard deviation; BRs – brassinolide

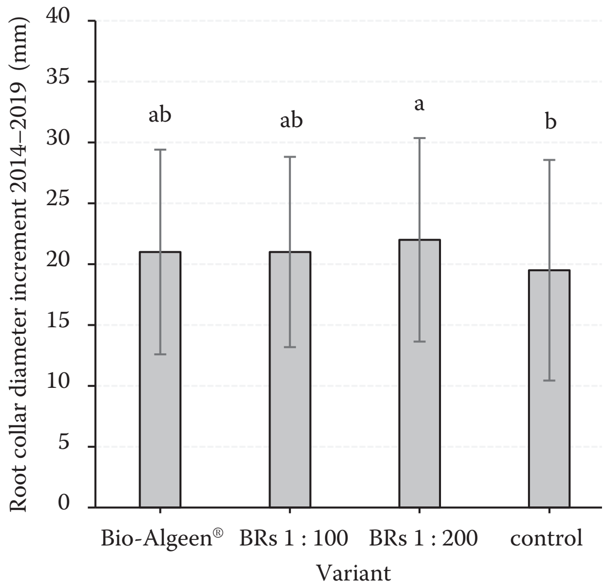

Figure 5. Median root collar diameter increment (mm) of different treatments of silver fir plantation in the period 2014–2019 on the research plot Truba

Different letters indicate significant differences according to Kruskal-Wallis multiple comparisons test; error bars – standard deviation; BRs – brassinolide

1 : 200 showed the highest value (32.2 mm), while BRs 1 : 100 and Bio-Algeen® reached 30.7 mm and 29.9 mm, respectively.

Height and root collar diameter increment. Total number of evaluated trees was 626. In height increment over the monitoring period, the Kruskal-Wallis test showed significant differences between variants (Kruskal-Wallis chi-squared = 12.371, df = 3, P-value = 0.006213). Subsequent Kruskal-Wallis multiple comparison test revealed that height increment of the variant treated with Bio-Algeen® was significantly lower than the growth of BRs-treated variants. All treated variants were comparable to control variant (Figure 4).

In evaluating the root collar diameter increment over the monitoring period, BRs 1 : 200 exhibited significantly higher increment in comparison with control treatment. However, it was not significantly different from BRs 1 : 100 or Bio-Algeen®, which were not significantly different from the control (Figure 5).

Vitality. Visually assessed vitality and colour are in Tables 4 and 5, respectively. In case of Bio-Algeen®, most trees were in vitality category B in 2014, but they shifted to C in 2015. In contrast, B remained the most abundant category in 2014 and in 2015 for BRs 1 : 100, even though the qual-

Table 4. Relative frequency (%) of silver fir individuals in different vitality classes according to different variants in 2014 and 2015 on the research plot Truba

Year	2014					2015				
Variant	A	B	C	D	E	A	B	C	D	E
Bio-Algeen®	34.66	40.91	17.61	4.55	2.27	7.10	23.30	39.49	7.10	23.01
BRs 1 : 100	38.07	53.98	6.25	1.14	0.57	8.52	28.41	25.57	10.23	27.27
BRs 1 : 200	46.29	40.57	12.00	1.14	0.00	20.00	24.57	25.71	5.71	24.00
Control	43.18	46.02	9.66	0.57	0.57	12.50	25.00	28.98	14.20	19.32

Vitality classes: A – excellent; B – good; C – somewhat worsened; D – significantly worsened; E – dry; BRs – brassinolide

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Table 5. Relative frequency (%) of *Abies alba* individuals in different colour classes according to different variants in 2014 and 2015 on the research plot Truba

Year	2014			2015		
Variant	1	2	3	1	2	3
Bio-Algeen®	34.6	60.2	5.2	66.1	27.7	6.3
BRs 1 : 100	37.7	58.9	3.4	58.6	31.3	10.2
BRs 1 : 200	41.7	56.0	2.3	70.9	23.1	6.0
Control	38.3	53.7	8.0	58.5	27.5	14.1

Colour classes: 1 – green, 2 – green-yellow, 3 – yellow; BRs – brassinolide

ity also heavily shifted to other categories. For BRs 1 : 200 in 2014, the most abundant category was A, but then C and B in the next year. For the control, a similar pattern like in other treatments was registered, i.e., shift from better to worsened vitality.

Regarding the visually assessed parameter – colour of previous year needles, the development was contrary to overall vitality – it mostly shifted from yellow-green in 2014 to green in 2015 in all variants (Table 3).

Economic analysis. Estimated results of the simple economic analysis are shown in Table 6. The input costs are the same (planting stock, outplanting, transport, weed control and fence), the differences are in the extra care of individual treatments. The most expensive was Bio-Algeen® treatment (total cost 5 254 EUR·ha^{-1}) compared to the cheapest control variant (5 224 EUR·ha^{-1}). The extra care of BRs variants was 10 EUR·ha^{-1} lower.

Relationship between increment, mortality, climate and treatments. Results of the principal component analysis expressing the relationship between seedling parameters, climate factors and fir treatments are presented in the form of ordination diagram in Figure 6. The first ordination axis represents

Table 6. Results of simple economic analysis comparing three different variants: Bioalgeen®, BRs and control at the experimental plantation of *Abies alba* at Truba research plot

Item / activity	Bio-Algeen®	BRs	Control
	(EUR·ha^{-1})		
Planting stock	2 222	2 222	2 222
Outplanting	2 222	2 222	2 222
Transport	80	80	80
Weed control	300	300	300
Fence	400	400	400
Extra care	30	20	0
Total	5 254	5 244	5 224

BRs – brassinolide

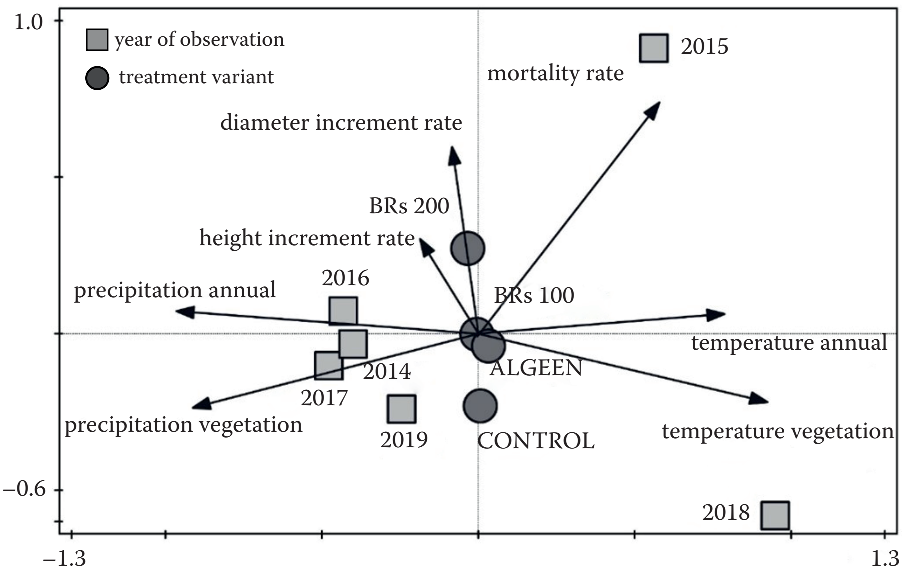

Figure 6. Ordination diagram showing results of principal components analysis of relationship between seedling parameters (root collar diameter increment rate, height increment rate, annual mortality rate), climate factors (annual temperature, temperature in vegetation period, sum of annual precipitation, sum of precipitation in vegetation period) and treatments (control, BRs 100, BRs 200 and Bio-Algeen®)

BRs – brassinolide

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48.24%, the first two axes 66.21% and the four axes together account for 95.20% of data variability. The x-axis represents the root collar diameter increment rate and the y-axis represents climate factors (air temperatures and sums of precipitation). Mortality rate of seedlings was increasing with decreasing sum of precipitation and increasing temperature. Height increment was positively correlated with root collar diameter increment. The lowest explanatory variable in the ordination diagram was height increment ratio. The differences between treatment variants were significant, compared to small differences between years in the period 2014–2019. Generally, BRs 1 : 200 treatment was the most suitable for the growth of silver fir compared to the control.

DISCUSSION

The existence of forests in many areas is threatened. An ideal way of the ecosystem preservation is natural dynamics and natural regeneration (Vacek et al. 2019; Brichta et al. 2020; Prokůpková et al. 2020; Fuchs et al. 2021; Hammond et al. 2021). These processes are not functional on many areas for different reasons. One of possible ways to save forests is artificial regeneration (reforestation) and afforestation on new non-forest areas and areas where forests were previously removed (Vacek et al. 2018, 2021a; Cavalli et al. 2022; Cukor et al. 2022; Zeidler et al. 2022). In such cases, intensive care is efficient to decrease the initial mortality of trees (Gallo et al. 2020). Moreover, afforestation plays a significant role in the mitigation of climatic changes due to the global carbon cycle (Cukor et al. 2017a).

In many cases, planting trees became a controversial topic (Chytrý et al. 2001). Phrases like "more harm than good" or "controversial strategy" are used regarding the effects of plantations on climate change and fires (Elbein 2019; Yanes 2020). Their effect on plant communities is also significant (Andrés, Ojeda 2002). It is important to understand historical context of deforestation, scale of original forest cover and all benefits of forests and trees.

A number of field experiments done as well as practical experience showed that the cultivation of climax species under the conditions of large-scale clear-cuts is difficult and much more demanding on post-planting care in comparison with the use of pioneer species which grow spontaneously on many sites (not on all however) (Eisenhauer et al. 2001; Martiník et al. 2018). It is up to the owners to decide whether they want to invest in more demanding measures. Silver fir requires fencing against game damage and often also weeding or at least weed control by trampling (Vacek et al. 2014; Vacek 2017; Gallo et al. 2020). Regeneration of fir is strongly influenced by vegetation cover. For example, Prokůpková et al. (2021) from Poland showed that the tallest fir regeneration individuals were observed in the *Rubus* cover, while the highest density of fir natural regeneration was observed in the moss cover. A number of papers also reported that a warm summer and repeated long-term drought with lower precipitation total had a significant negative impact on the vitality and health of silver fir (Thomas et al. 2002; Camarero et al. 2011; Linares 2011; Linares, Camarero 2012; Büntgen et al. 2014; Gazol et al. 2015; Vejpustková et al. 2023). Similarly, a high mortality rate was observed in our study in 2015 (second year after planting) due to the synergism of extremely high air temperature in vegetation and droughts.

BRs 1 : 200 treatment performed the best in relation to mean root collar diameter, as well as vitality and colour changes under drought stress. It is in accordance with previous research, where a particular concentration of BRs performed better than the control, but different concentration performed worse (Nováková et al. 2015). However, the results of different studies are inconsistent. BRs also showed a positive effect on overcoming drought stress in the germination of Norway spruce, Scots pine (*Pinus sylvestris* L.) and Douglas fir (Kuneš et al. 2016). BRs had negative effects on growth and mortality of Scots pine in another study (Nováková et al. 2014).

Bio-Algeen® treatment showed lower height increment in comparison with BRs treatments, but comparable with the control variant while showing root collar diameter increment comparable with all other variants. Benefits of Bio-Algeen® were therefore not proven. Study by Lorenc et al. (2016) recommended Bio-Algeen® for application in forest nurseries, as its application boosted growth. Similarly, another study showed positive economic and production results regarding the application of Bio-Algeen® to seedlings in both nursery and plantation site (Hanzal et al. 2015). Another way of applying algae-related material is the application of alginite rocks (Tužinský et al. 2015; Cukor et al. 2017b, c).

The simple economic analysis showed moderate differences in costs over the variants, as the additional substances are not crucial in the inputs,

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especially in comparison with the costs of planting stock and labour. On the other hand, from the ecological point of view, the ameliorative effects of silver fir are not clearly determined, in most factors it has better results than Norway spruce, but not very convincingly and its sensitivity to environmental conditions is problematic (Třeštík, Podrázský 2017; Podrázský et al. 2018).

There are still many questions regarding the research of BRs and Bio-Algeen®. What about the effects of the combination of those substances? What about combining BRs and Bio-Algeen® with different fertilizers or alginite rocks? There are many possible combinations of different substances to enhance growth and vitality of young forest plantations. Such activities of initial care are aimed at creating more diverse and stable ecosystems in future, ensuring their functionality in later stages using mostly silvicultural measures (Vacek et al. 2020).

CONCLUSION

Silvicultural measures to support biodiversity are crucial for nature protection under the current conditions of intensive human impact on forest ecosystems and ongoing climate change. In this experiment, the plantation of target tree species *Abies alba* was treated with a brassinolide compound and with Bio-Algeen® alongside with the control variant to find the best possible treatment for optimized growth and vitality of this infrequent species. The plantation showed stable growth and vitality and minimal rates of mortality, except the year 2015 with hot and dry summer. None of the treated variants showed significantly better values of growth and mortality in comparison with the control. Therefore, we cannot confirm the hypothesis that brassinolide compound or Bio-Algeen application increased growth and vitality and decreased mortality of silver fir plantation. Regarding the economic aspect, control variant is the cheapest, missing all additive operations, but there can be some benefits brought by additional chemicals like improved radial growth, vitality and colour under stressful conditions. With the combined knowledge and practice of natural regeneration support, as well as intensive care of the plantation of valuable target species, it is possible to preserve and even extend the areas of fully functional forest ecosystems. Depending on the level of previous transformation of forest stands, different methods of afforestation and management intensity might be used. On suitable sites, it is possible to cultivate rare and demanding tree species directly without the preparatory stage of forest. Silviculture is the only tool to reintroduce rare tree species to places where they have been missing for a long time due to previous human activity and impact.

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