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REGENERATION OF SILVER FIR (*ABIES ALBA* MILL.) ON CLEAR-CUT AREAS

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Abstract

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The paper evaluates the growth of Silver fir plantations on clear-cut areas in the regime of different sheltering and mixing with the European larch. The experiment was carried out on a permanent research plot where Silver fir was planted on an unsheltered open space, on an open space sheltered by the gradually overgrowing European larch, alternating in rows and mixed within the row with the gradually overgrowing European larch. It was also planted in a SW corner of the clear-cut area sheltered on two sides by a mature spruce stand. Results of measurements demonstrated that the conditions of the unsheltered clear-cut area or only partly sheltered clear-cut area have no principal adverse influence on the growth of Silver fir. However, a considerably higher mortality, more severe frost injury and impaired vitality of plants were observed. The most suitable option for the regeneration of Silver fir on a clear-cut area, i.e. the option in which Silver fir individuals would exhibit good growth, low mortality, low frost injury and high vitality (needle length and colour) appeared to be the plantation of Silver fir in mixed rows with the European larch (N-S direction of rows), where the larch starts to overgrow the fir very rapidly, thus providing the necessary shelter. Pure fir groups are then recommended to be planted in marginal stand parts that are sheltered for a greater part of the day by the surrounding stand.

Keywords: Silver fir, regeneration, clear-cut area, European larch

INTRODUCTION

Silver fir (*Abies alba* Mill.) is a domestic species in the Czech Republic, which forms an important constituent in the natural species composition of forest stands (ZATLOUKAL, 2001) namely in mountain regions but in lower elevations, too (KANTOR, 2001). Its share has dramatically decreased due to large-scale cutting, clear-felling system, air pollution, impact of noxious agents and inadequate natural regeneration (ZATLOUKAL, 2001). Silver fir recorded a rapid withdrawal in Central Europe at the turn of the 18th and 19th centuries and in the second half of the 19th century in particular, especially due to the gradual expansion of clear-felling system and increasing introduction of spruce and pine planting (KORPEĽ, VINŠ, 1965). While in the past, fir was the most abundant coniferous species in the territory of the today's Czech Republic with its share of nearly 20% in the natural species composition of the forest stands (MUSIL, HAMERNÍK, 2007), its current proportion of total timberland area in the Czech Republic is approximately only 1% (MZE ČR, 2012). The disastrous decrease of the species and the total change in the species composition of our forest stands is obvious by comparing the data (KORPEĽ, VINŠ, 1965). According to the concept of the target composition of species in the Czech forests, the proportion of fir should increase to 3% and 5% within the next 50 and 100 years, respectively (KANTOR, 2001). This means that the regeneration of Silver fir during one rotation period should be realized and established on an area of 130,000 ha (i.e. on an area of ca. 1,300 ha per year). Notwithstanding the fact that the natural regeneration of Silver fir has increased in recent years, the objective can be in no case achieved merely through natural regeneration regarding the extent of damages on the fir stands and their small representation. In this case, artificial regeneration plays an irreplaceable role. Although some objections exist in respect of the artificial regeneration of fir on clear-cut areas, this regeneration method has to be taken into account

at the present time for re-introducing the fir in the areas of its original occurrence (KORPEĽ, VINŠ, 1965).

Silver fir is known for its good capacity to endure shade. However, its light requirements are conditioned by a range of other climatic factors such as rainfall, temperature, air humidity, soil moisture content, air flow and soil character. The more favourable the site conditions are, the lower are the species' light treat requirements. By contrast, at higher and colder elevations and/or on drought-prone soils poor in minerals as well as on the lower boundary of its range, the light requirements of fir are markedly higher (SVOBODA, 1952). The mean annual temperature should not fall below 5–8 °C, and the average air temperature in summer months should be at least 12–15 °C (KORPEĽ, VINŠ, 1965). The successful growth and development of fir needs favourably high relative air humidity and namely sufficient precipitation of at least 350–400 mm in the growing season. This is why the species is susceptible to drought spells but also to harsh winters, late frost and atmospheric circulation. Therefore, the silver fir can be considered as our most sensitive and most demanding coniferous tree species because in addition to the above-mentioned requirements for humidity and warmth, its prosperous growth needs also deep, nutrient-rich and loose soils (KADLUS, ZAKOPAL, 1975; SOKOL, 1956). Agents impairing fir plantations on clear-cut areas are temperature fluctuations, early and late frosts, increased air circulation with high evaporation and exchange of gases (KORPEĽ, VINŠ, 1965).

In the conditions of the Czech Republic, the artificial regeneration of Silver fir can be implemented by three methods. The first one is planting under the parent stand shelter in the form of small-scale shelterwood felling operations (patches, wedges, strips), or on the inner margin of the shelterwood felling. The second option is Silver fir regeneration on the border felling regeneration elements (patches, wedges or strips) with the required protection against the direct solar radiation achievable by properly adjusting the width and orientation of the applied cuts. The third option is Silver fir regeneration on classic clear-cut areas. Although many authors (KORPEĽ, VINŠ, 1965; KADLUS, ZAKOPAL, 1975) mention from their experience and observations a number of successful cases of Silver fir regenerated on the clear-cut area, this method of artificial regeneration is generally not recommended (KANTOR, 2001).

The study evaluates the growth of Silver fir plantations in gaps under conditions of different sheltering and mixing with the European larch.

MATERIAL AND METHODS

The "Stašov" permanent research plot with the experimental Silver fir plantation is situated in the Stand 263B11b (Forest District Svitavy, Ward Radiměř) owned by Lesy České republiky, s. p. (Forests of the Czech Republic, State Enterprise). The typological situation of the site is characterized as the primary management group 431 – spruce management of acidic sites at mid-elevations, forest type 5K7 – acidophilous Fir-Beech with hair-grass and oxalis. Quartz sandstones and feldspathic sandstones form the geological bedrock. The soil type is mesotrophic brown forest soil. The altitude of the experimental plot ranges from 640–660 m a.s.l., slope ca. 15%, NNW aspect.

In the winter period of year 2004, the original spruce stand was felled on an area of 2.17 ha and the plot was fenced. About a half of the plot was used to study the influence of sheltering and mixing on the growth of Silver fir. Forestation was made in 2006 by hole planting (patches 25 × 25 cm) with bare-rooted fir transplants (age 5 years – 2 + 3, shoot length 40 cm). Moreover, containerized and balled transplants of European larch (age 2 years – f1+k1, shoot length 36–50 cm) were planted on a part of the research plot – see individual experimental variants below. The direction of the planted rows was N-S. All experimental variants included transplants of the same origin, same parameters, grown in the same nursery; the plots were not further improved. Individuals of European larch started to overgrow individuals of Silver fir immediately after planting, thus providing a shelter for them against direct sun rays on the respective variants; in 2012, the height of the European larch (after six years of growth) reached 470–540 cm. Experimental variants of Silver fir plantations established on the research plot were as follows:

Variant CC – Silver fir was planted in an open space in the middle of the clear-cut area at a spacing 2 × 1.7 m (3,000 individuals per hectare).

Variant LL – Silver fir was planted at a spacing 2 × 1.7 m (3,000 individuals per hectare) in an open space, which was gradually becoming sheltered by the overgrowing larch stand; distance from the edge of the European larch stand up to 13 m.

Variant RL – Silver fir and European larch were planted in mixed (alternating) rows (SF/EL/SF/EL) at a spacing 2 × 1.7 m (3,000 individuals per hectare).

Variant LiR – Silver fir and European larch were planted as mixed (alternating) individuals (SF-EL-SF-EL) within each row at a spacing 2 × 1.7 m (3,000 individuals per hectare).

Variant SE – Silver fir was planted at a spacing 2 × 1.7 m (3,000 individuals per hectare) in an open space, which was sheltered on two sides by a mature spruce stand. The firs were planted from the SW corner of the clear-cut area, which was for the most of the day sheltered against the direct solar radiation – plot size ca. 160 m^2.

The objective of establishing the research plot was to ascertain the influence of sheltering and type of mixing on the growth, morphological quality and vitality of Silver fir transplants, i.e. whether and under what conditions the species can be planted on clear-cut area. Parameters established in Silver fir individuals after the end of growth at the end of year 2012 (6 years after planting out) were as follows:

1. Above-ground height (cm).
2. Root collar diameter (mm) ca. 10 cm above the soil surface.
3. Height increment (cm) in the last three growing seasons (2010, 2011, 2012).
4. Length (cm) and base diameter (mm) of the longest branch.
5. Average length of needles (mm) – measured were 3 needles occurring in the middle of the most recent gain of the third whorl branch (from the top).
6. Stem form: 1. normal stem, 2. twin stem, 3. triple stem, 4. more than three stems.
7. Crown form: 1. normal, 2. cubical, 3. spherical, 4. flag-shaped (one-sided), 5. clumped setting of branches in the lower part of the crown, 6. cup-shaped.
8. Needle biomass colour: 1. dark green, 2. green, 3. light green, 4. yellow.
9. Injury – frost injury (evaluated once in 2012) and damage due to abiotic agents.
10. Mortality.

Depending on the size of the individual experimental variants (number of planted individuals), we measured either all planted individuals (Variants 3, 4 and 5) or individuals in every other row (Variants 1 and 2). The number of measured plants in the respective variants ranged from 120–320 individuals. In the Variant 5, which was of a smaller size due to specific stand conditions, we measured only 49 individuals.

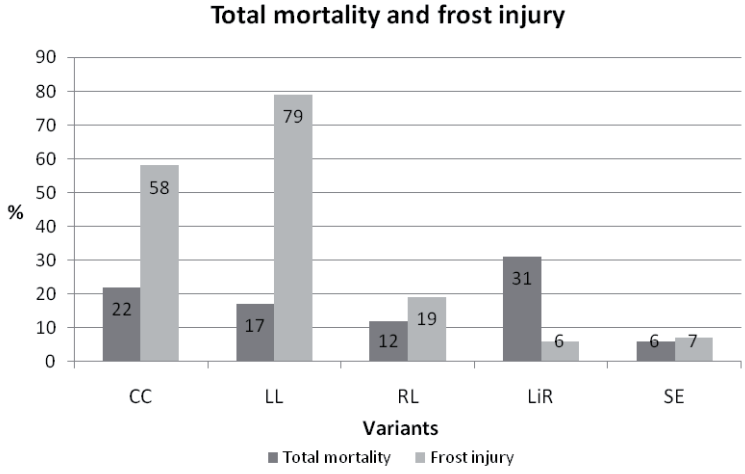
In samples from the respective variants, we first ascertained the basic data prerequisites (normality, independence of individual elements etc.). Then we calculated the descriptive statistics, and the sets of data were subsequently compared by using statistical tests (single-factor ANOVA, multiple comparison test – HSD for dissimilar numbers of elements). All tests were conducted at a significance level $\alpha = 0.05$. The data were statistically processed in the Statistica 10 programme and the additional inquiries in the Excel 2007 (MS Office).

RESULTS

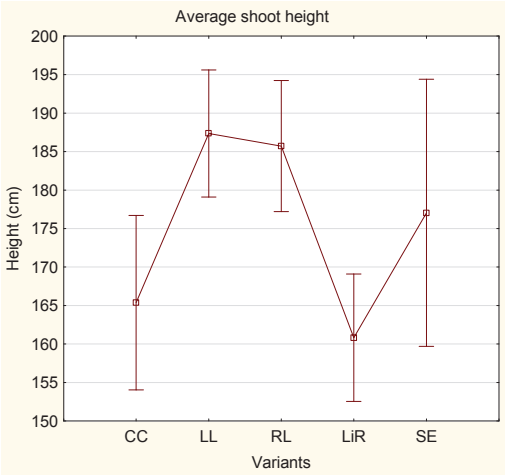
Total mortality six years after planting and frost injuries are shown in Fig. 1. The mortality of transplants in the respective variants of plantations ranged from 6 to 31%. The lowest total mortality (6%) was recorded in the SE variant (Silver fir planted in the corner of the gap sheltered on two sides by the neighbouring mature stand). The highest total mortality (31%) was observed in the LiR variant where Silver fir and European larch individuals were alternating within the row, and in the CC variant (22%), where Silver fir was planted in an open space on the clear-cut area.

Frost injury was recorded in all planted variants with the lowest damage being observed in the LiR variant (Silver fir mixed with European larch within the row) – 6%, and in the SE variant (Silver fir planted in the corner of the clear-cut area) – 7%. The highest frost injury was recorded in the LL variant (Silver fir planted in the open space with the lateral shelter provided by the overgrowing larch) – 79%, and in the CC variant (open space in the clear-cut area) – 58%.

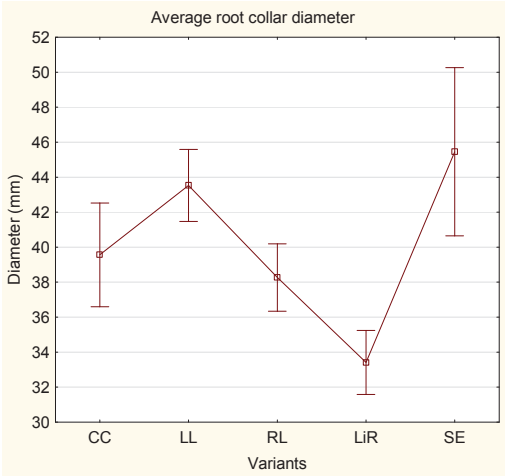
Comparing the above-ground length of individuals in the respective variants (see Tab. I, Fig. 2), we found out statistically significant differences among the respective variants. The greatest average height was recorded in the LL variant (Silver fir planted in the open space with the lateral shelter provided by the overgrowing larch) and in the RL variant (Silver fir and European larch planted in alternating rows). On the other hand, the smallest average height was recorded in the LiR and



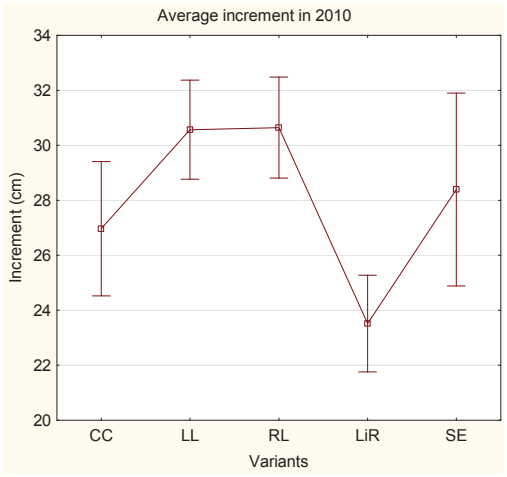
1: *Total mortality and frost injury in the respective variants*



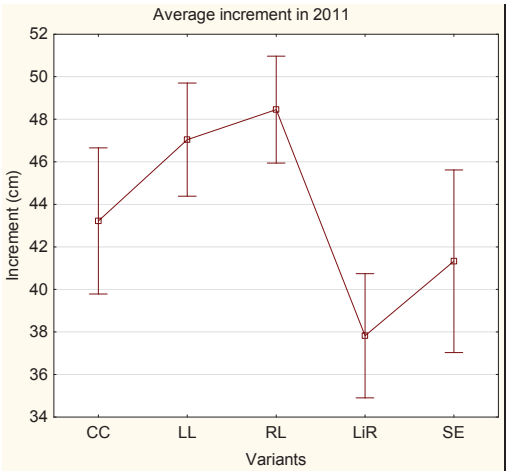
2: *Average shoot height*



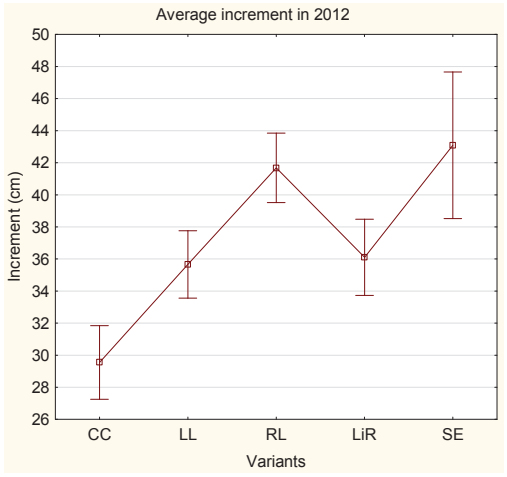
3: *Average root collar diameter*



4: *Average increment in 2010*



5: *Average increment in 2011*



6: *Average increment in 2012*

CC variants (mixing within the row and planting in the open space) where the LiR variant exhibited the height significantly lower than all the other variants. The SE variant (Silver fir planted in the corner of the clear-cut area and sheltered on two sides by the mature spruce stand) ranked with the above two couples of variants (LL, RL and LiR, CC) in terms of its average height. However, it did not differ significantly from all other plantation variants due to relatively great data dispersion (see Tab. III).

Comparing the root collar diameter (see Tab. I, Fig. 3), we found out that the lowest average root collar diameter was recorded in Silver fir transplants growing in the LiR variant (Silver fir and larch mixed within the row) where the diameter was significantly lower than in all other variants. The largest average root collar diameter was observed in the SE variant (Silver fir planted in the corner of the clear-cut area). Nevertheless, due to great data dispersion, this variant differed significantly only from the LiR variant (Silver fir mixed with larch within the row). The second largest average root collar diameter was recorded in the LL variant (Silver fir planted in the open space with the lateral shelter provided by larch), where individuals showed a significantly larger average root collar diameter as compared with the LiR and RL variants (see Tab. III).

I: *Mean height, root collar diameter and increment in 2010, 2011 and 2012*

Variant	Mean height	Mean root collar diameter	Mean increment 2010	Mean increment 2011	Mean increment 2012
	(cm)	(mm)	(cm)	(cm)	(cm)
1.CC	165.4	39.6	27.0	43.2	29.5
2.LL	187.4	43.5	30.6	47.0	35.7
3.RL	185.7	38.3	30.6	48.5	41.7
4.LiR	160.8	33.4	23.5	37.8	36.1
5.SE	177.0	45.5	28.4	41.3	43.1

II: *Mean length of needles, length and diameter of the longest branch*

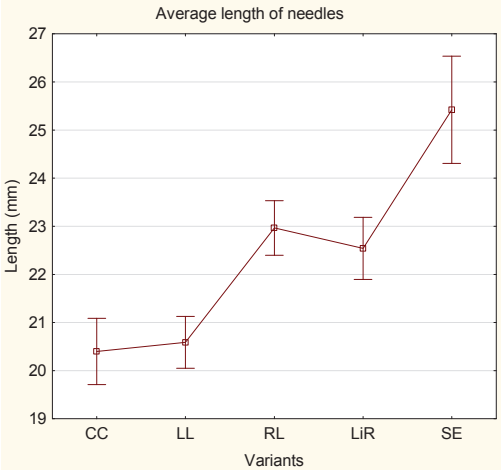
Variant	Mean length of needles	Mean length of the longest branch	Mean diameter of the longest branch
	(mm)	(cm)	(mm)
1.CC	20.4	64.4	11.2
2.LL	20.7	71.8	12.6
3.RL	23.0	69.8	11.1
4.LiR	22.5	64.5	10.5
5.SE	25.4	76.1	12.5

The comparison of the average increment of Silver fir individuals in the respective variants in 2010, 2011 and 2012 (see Tab. I, Fig. 4, Fig. 5, Fig. 6) showed that results in the growing seasons of years 2010 and 2011 were much similar. In the two years, the lowest average increment was recorded in the LiR variant (mixing with larch within the row). By contrast, the highest average increments were recorded in the two years in the RL variant (fir and larch in alternating rows) and in the LL variant (open space with lateral shelter by larch). The difference between these two variants was non-significant; as compared with the above-mentioned LiR variant (mixing with larch within the row), both variants exhibited significantly higher increment but did not differ significantly from the other variants. However, the average increment of individuals for the year 2012 differed from the preceding two growing season; with the exception of variant SE (Silver fir planted in the corner of the clear-cut area), all the other variants exhibited the increment lower than in the preceding years. The lowest average increment (significantly lower than in the other variants) was recorded in the CC variant (open space). By contrast, the highest average increment was recorded in the SE variant (Silver fir planted in the corner of the clear-cut area) and in the RL variant (fir and larch in alternating rows). Due to great data dispersion, the SE variant significantly differed only from the CC variant, and the RL variant exhibited – apart from the SE variant- the increment significantly higher than all the other variants (see Tab. III).

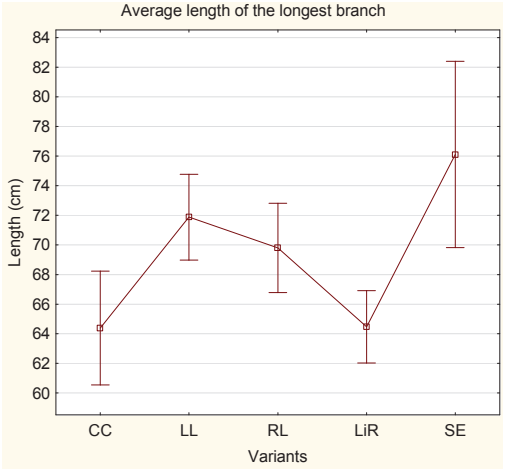
If we compare the average length of needles in the respective planting variants (Tab. II, Fig. 7), we will find out that firs in the variants CC (open space) and LL (open space with lateral shelter by larch) had the lowest values, which were significantly lower than those in the other variants were. On the other hand, the greatest average length of needles (significantly higher than in the other variants) was recorded in the SE variant (Silver fir planted in the corner of the clear-cut area).

Comparing the average length of the longest branches of individuals in the respective variants (see Tab. II, Fig. 8), we found out that the highest values were reached by individuals growing in the SE variant (Silver fir planted in the corner of the gap) and in the LL variant (open space with lateral shelter by larch). By contrast, the lowest values were recorded in individuals from the CC variant (open space) and LiR (fir and larch alternating within the row) with the difference from the above-mentioned variants SE and LL being statistically significant.

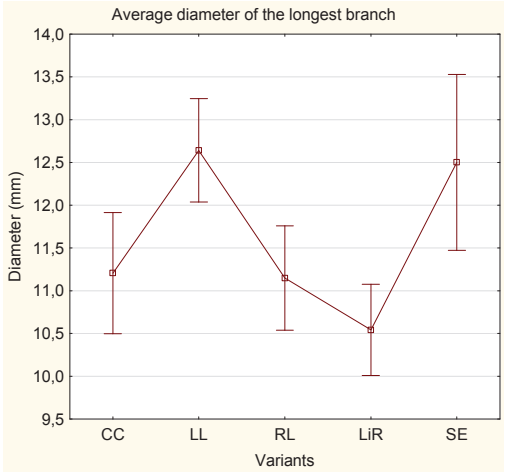
The evaluation of the average diameter of the longest branches brought similar results (see Tab. II,



7: *Average length of needles*



8: *Average length of the longest branch*



9: *Average diameter of the longest branch*

III: *Homogeneous groups for the individual measured characteristics of Silver fir ascertained by HSD test with dissimilar numbers of elements (group without significant differences is formed by variants marked with asterisk in the respective columns)*

Variant	Mean height (cm)	Homogeneous data groups without statistically significant differences			Variant	Mean diameter (mm)	Homogeneous data groups without statistically significant differences		
		1	2	3			1	2	3
LiR	160.8	****			LiR	33.4			****
CC	165.4	****	****		RL	38.3	****		
SE	177.0	****	****	****	CC	39.6	****	****	
RL	185.7		****	****	LL	43.5		****	
LL	187.4			****	SE	45.5	****	****	

Variant	Mean increment 2010 (cm)	Homogeneous data groups without statistically significant differences		Variant	Mean increment 2011 (cm)	Homogeneous data groups without statistically significant differences	
		1	2			1	2
LiR	23.5		****	LiR	37.8		****
CC	27.0	****	****	SE	41.3	****	****
SE	28.4	****	****	CC	43.2	****	****
LL	30.6	****		LL	47.0	****	
RL	31	****		RL	48	****	

Variant	Mean increment 2012 (cm)	Homogeneous data groups without statistically significant differences			Variant	Mean length of needles (mm)	Homogeneous data groups without statistically significant differences		
		1	2	3			1	2	3
CC	29.5			****	CC	20.4	****		
LL	35.7	****			LL	20.6	****		
LiR	36.1	****			LiR	22.5		****	
RL	41.7		****		RL	23.0		****	
SE	43	****	****		SE	25			****

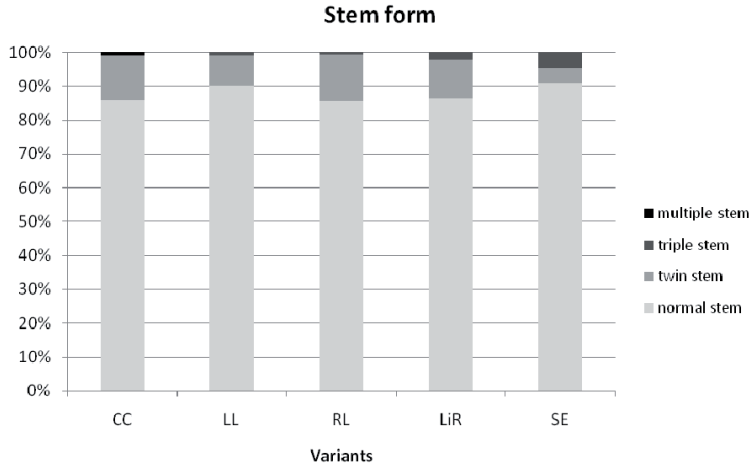
Variant	Mean length of the longest branch (cm)	Homogeneous data groups without statistically significant differences		Variant	Mean diameter of the longest branch (cm)	Homogeneous data groups without statistically significant differences	
		1	2			1	2
CC	64.4	****		LiR	10.5	****	
LiR	64.5	****		RL	11.1	****	
RL	69.8	****	****	CC	11.2	****	
LL	71.9		****	SE	12.5	****	****
SE	76		****	LL	13		****

Fig. 9); the highest values were recorded once again in the LL variant (open space with lateral shelter by larch) and in the SE variant (Silver fir planted in the corner of the gap). The LiR variant (fir and larch alternating within the row) and the RL variant (fir and larch in alternating rows) exhibited the lowest values.

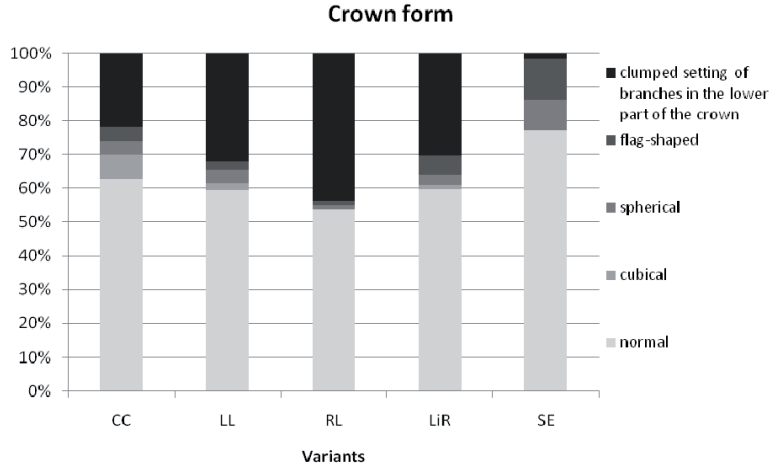
The diagram in Fig. 10 shows that the stem form of Silver fir individuals did not differ essentially in the respective variants of planting. Nevertheless, a general statement can be made that the SE variant (Silver fir planted in the corner of the gap) – 91% of normal stem forms, 4.5% twin stems, 4.5% triple stems, and the LL variant (open space with lateral shelter by larch) – 90.3% of normal stem forms, 8.7% twin stems, 1% triple stems, exhibited the best results. The remaining three variants had very similar results with the proportion of normal stem forms ranging from 85% to 86.3% and the share of twin stems from 11.5% to 13.6%. The CC variant (open space) was the only one with the occurrence of multiple stem individuals.

The diagram in Fig. 11 presents the proportions of Silver fir individuals with different crown form types and shows that the highest share of individuals with the normal crown form type occurred in the SE variant (Silver fir planted in the corner of the gap) – 77%. In the other variants, this figure was markedly lower with the RL variant (fir and larch planted in alternating rows) exhibiting the lowest proportion of normal crowns – only 53.8%.

The diagram in Fig. 12 presents the colours of the needle biomass of transplants growing in the respective variants of planting. The best results in this respect were achieved by Silver firs in the SE variant (Silver fir planted in the corner of the gap) with 36% of individuals exhibiting dark green, 57% green and 7% light green needles and no individuals with yellow needles. On the other hand, the worst turned out to be the CC variant (open space) and the LL variant (open space with lateral shelter by larch) with the lowest share of individuals with dark green needles (10% and 6%, resp.), the highest proportion of light green needles (45% and 41%, resp.) and the identical share of yellow needles (4% both).



10: *Stem form of Silver fir individuals in the respective variants*



11: *Crown form of Silver fir individuals in the respective variants*

The complex analysis of measured data and studied characteristics revealed the existence of considerable differences among the individual variants of planting Silver fir on the clear-cut area as early as already six years after the planting.

Assessing the growth and qualitative parameters, we found very good results in the SE variant of planting (Silver fir planted in the corner of the gap). Although the variant did not rank at all times with the best ones in terms of height, diameter and increment, it exhibited the lowest mortality, the second lowest frost injury and in the parameters of stem form, crown form and colour of needle biomass it was evaluated as the best one. These facts demonstrate that ecological conditions created by planting the Silver fir in the corner of the clear cut area, which is for the most of the daytime sheltered against the direct solar radiation by the adjacent stand are very favourable for the species. Such a variant of planting is a good prerequisite for the formation of a high-quality stand. Other variants showing good results in the evaluation of growth parameters were the RL variant (fir and larch planted in alternating rows) and the LL variant (Silver fir planted on an open space with lateral shelter by larch). However, from the perspective of mortality, frost injury and colour of needles, the LL variant exhibited relatively poor results. By contrast, the RL variant achieved good results with only 19% of individuals injured by frost, which demonstrated the beneficial influence of Silver fir sheltering by larch. The CC variant (planting on an open unsheltered space) did not exhibit in principle poor results; by average height, diameter and increment it many a time equalled the individuals in the other variants. Nevertheless, in terms of mortality, frost injury and namely the colour of needles (vitality), it was one of variants with the worst results. The LiR variant (fir and larch alternating within the row) exhibited surprisingly poor results in nearly all growth parameters showing, however, the best results in the evaluation of frost injury and the second best results in the evaluation of the colour of needle biomass. These results demonstrate that this type of mixing is likely to have a positive effect on the vitality of surviving individuals (colour of needles) but the level of shading (Silver fir individual being sheltered by European larch individuals from all sides) makes the fir to respond by suppressed growth.

DISCUSSION

The main currently recommended methods for the artificial regeneration of Silver fir include planting under the shelter of the parent stand and planting within small clear felling regeneration elements – cutting faces (KANTOR, 2001). Both methods have a task to bring the microclimatic stand conditions closer to the requirements of Silver fir. From the ecological point of view, the regeneration elements conform to the fir for maintaining soil and atmospheric moisture as well as optimal light supply. Lateral protection, which provides for air still-stand in the ground layers of the stand, can be maintained in these conditions, too (KORPEĽ, VINŠ, 1965).

On the other hand, the planting of Silver fir directly on the unsheltered clear-cut area is one of methods of artificial regeneration, which is not advised with respect to the species' ecological requirements (JASZCZAK, 2008; KANTOR, 2001; KOŠULIČ, 2003; PEŘINA, 1977). A majority of foresters engaged with the regeneration of fir condemn this regeneration method as not conforming the species' biological strategy and many of them consider the clear-felling system with artificial regeneration as one of reasons for the species' rapid disappearance in the last century (MÁLEK, 1983; MRKVA, 1994). Results from the discussions of many authors can be summarized in a recommendation to regenerate the Silver fir as a shade-bearing climax woody plant exclusively under the protection of regenerated stands and/or under a shelter of earlier established preparatory stands, preferably with using the pioneer species (ŠINDELÁŘ, FRÝDL, 2005).

Nevertheless, even in respect of planting Silver fir on a clear-cut area, there are opinions and experiences that the method not always has to fail and that the generally established rule about the necessity of shading the species in its earliest developmental stages can be considered outdated (JANKOVSKÝ, CETKOVSKÝ, 2005). The relatively high tolerance of young age stages of the firs of different origins to direct solar radiation can be documented also from the results of long-term growth studies conducted on research provenance plots (ŠINDELÁŘ, FRÝDL, NOVOTNÝ, 2004). LISNÍK (2003) informs in his paper about his experience with regenerating fir on a clear-cut area. He claims that the capacity of the species to grow in shade connects with a sufficient amount of precipitation and that in regions with low precipitation amounts, it is better to regenerate the fir on the margin of the parent stand or even outside the parent stand on a clear-cut area. According to his experience, the fir may behave otherwise than as a shade-bearer, and if certain conditions are fulfilled, it can be artificially regenerated with success even on the clear-cut area. The author achieved the best results on plots prone to the infestation by herbaceous and shrubby vegetation, which gives the fir a lateral shelter with low air movements during the initial stages of growth. Other authors admit a general possibility of regenerating fir on gaps, too (KORPEĽ, VINŠ, 1965; ZATLOUKAL, 2001). They point out, however, that a necessary condition is to use some of means improving the microclimate of the clear-cut area, e.g. sheltering of plants against sunshine from the south by planting behind the stump, mowing to high stubble, placing fir plants near the stand edge, proceed with the stand regeneration from the north, or to use individual wooden sunshades. Many other authors argue that these observations are grounded usually only on

the sound growth of the fir at juvenile age while the question of the future development of these stands remains open (KANTOR, 2001). Because in their opinion, it is not only important how fast the long-lived fir grows at young age but also whether its vitality and productivity can keep the whole life and if ever it would survive until the high age that would correspond to its biological nature (KOŠULIČ, 2005B). At the same time, KOŠULIČ (2002, 2005A) adds that measuring the success of regeneration only by the growth rate of young plantations can be misleading. He points out that from the biological point of view, a rapid increment of fir and other climax species on the clear-cut area is characteristic at the most for a so-called "pioneer component of the population" which emerges as a genetic response to unfavourable influences of the growth environment. This would support the survival of flexible (pioneer-oriented) individuals while the climax part of the population would be more or less withdrawing.

The artificial regeneration of Silver fir on clear-cut areas in conditions of the Czech Republic is a lively discussed theme in the country, dividing the forest community into two groups. Results of our research with the experimental planting of Silver fir on a clear-cut area at various kinds of shelter and mixture partly identify with the experience and opinions of both these groups. We maintain that the planting of Silver fir directly on the unsheltered clear-cut area or on an open space sheltered on sides by the gradually overgrowing larch is feasible. Individuals in these experimental variants did not exhibit essentially impaired growth. Nevertheless, the gap environment unfavourably affects the Silver fir individuals by increased mortality and frost injury – these plantations suffer considerable damage and at the same time, they show the poorest vitality (needle length and colour). A different situation arises if the young plantation is protected by some way against these adverse effects. In our case, this concerns the planting of Silver fir in the NW corner of the gap, which is for the most of the day sheltered against the direct solar radiation (the plantation was sheltered on two sides by a mature spruce stand). The same holds for the rows with the alternating fir and larch where the early rapid growth of larch provides a necessary shelter for the young plants of Silver fir. In these variants, the Silver fir transplants successfully grow, their mortality and frost injury are markedly lower than in the other above-described planting variants, and the plants show good vitality (needle length and colour). Also DOBROWOLSKA (2008) found optimal conditions for fir development under larch canopy.

Our research results demonstrate that the planting of Silver fir directly on an unsheltered clear-cut area is possible. Nevertheless, in order to minimize the mortality, frost injury and to support vitality, it is advised to provide the species a shelter against the direct solar radiation and the above-mentioned impacts.

CONCLUSIONS

Increasing the share of Silver fir in forests of the Czech Republic is desirable. In the future hundred years, the species' proportion should increase to 5%. This means that in one rotation period, Silver fir should be regenerated and established on about 130,000 ha. In no case, the process will do without the artificial introduction of the species into forest stands.

A series of experimental plantations was established with different forms of sheltering and mixing with European larch in order to assess possibilities of planting the Silver fir on clear-cut areas. The experimental plantations were assessed six years after planting. Although a complex evaluation of these experimental Silver fir plantations on the gaps would call for additional research in the future, some partial results can be formulated already now. The results of studying the individual planting variants in the juvenile period can be summarized in the following explicit conclusions. The planting of fir on an unsheltered gap does not show a distinctly negative influence on the species' growth; however, the conditions of the clear-cut area contribute to increased mortality and frost injury, and impair the vitality of the plants. Because of this reason, it is advised to plant the Silver fir in clear-cut areas so that a shelter is provided, which would protect the young plants against the direct solar radiation. In our experiment, the advantage was proven of planting Silver fir in alternating rows with European larch (N-S direction of the rows), which rapidly starts overgrowing the Silver fir, thus forming the required shelter. Marginal (corner) stand parts that are for the most of the day sheltered by the surrounding stand are then advised to be planted with the pure fir groups.

SUMMARY

There are only a few recent scientific studies dealing with the growth of Silver fir on the clear-cut areas. Our research aimed at an evaluation of the growth of Silver fir plantations on the clear-cut area in the regime of diverse sheltering and mixing with European larch. For this purpose, a permanent research plot was established in the Forest District Svitavy, Ward Radiměř, where Silver fir was planted on an open unsheltered space, on an open space sheltered on the side by the gradually overgrowing larch, and in the south-western corner of the clear-cut area, sheltered on two sides by a mature spruce stand. Individuals growing in these variants were assessed six years after planting for height, stem diameter, height increment, length and diameter of the longest branch, length of needles, form of stem and crown, colour of needle biomass, frost injury and mortality.

Evaluating the above parameters and characteristics, we found out that the variant of planting into the corner of the clear-cut area (SE) showed very good results. This variant exhibited very good growth, the lowest mortality, the second lowest frost injury and in the parameters of stem form, crown form and colour of needle biomass it was classified as the best. Other variants with good results in the growth parameters were RL (fir and larch planted in alternating rows) and LL (Silver fir planted in open space with lateral shelter by larch). Nevertheless, as to mortality, colour of needles and frost injury, the LL variant exhibited relatively poor results. By contrast, the results of the RL variant were good – only 19% of Silver fir individuals were affected by frost injury thanks to the beneficial effect of their sheltering by larch. The CC variant (open unsheltered space) did not show in principle worse results than the other variants; it was however one of the worst variants in terms of mortality, frost injury and particularly the colour of needles (vitality). Surprisingly poor turned out to be in nearly all growth parameters the LiR variant (fir and larch alternating within the row). On the other hand, this variant showed the best results in the frost injury and the second best results in the colour of needle biomass.

We can conclude that in our experiment, the best variant was that of planting the Silver fir in alternating rows with the European larch (N-S direction of rows), which starts to overgrow the fir transplants soon, thus providing the necessary shelter. Marginal (corner) stand parts that are for the most of the day sheltered by the adjacent stand are then advised to be planted with the pure fir groups.

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