Influence of Shelterwood and Ground Vegetation on Late Spring Frost Damages of Planted Beech (*Fagus sylvatica*) and Douglas-Fir (*Pseudotsuga menziesii*) Saplings

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Abstract

Effects of shelterwood and two types of low vegetation cover (shrubs and gramineous) on frost occurence and degree of damages were investigated in young beech (*Fagus sylvatica* L.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) plantations.

A late frost event was registered at the end of April 2007 which did not affect saplings below a spruce shelterwood (on strip cutting or target diameter cutting plots), but frost damages occurred in open field conditions (on clear cutting plots).

The probability of frost damage occurrence increased significantly with light availability in both species, whereas the degree of frost damages (%, proportion of damaged beech leaves and damaged new Douglas-fir needles) decreased with increasing seedling height for both species.

A significant influence of field vegetation type (shrubs and gramineous) on the probability of frost occurrence could be detected in beech: in small shrubs the probability was lower than in gramineous species (0.48 vs. 0.76). The degree of frost damage decreased from gramineous to small shrubs type in both species, but significantly only in Douglas-fir saplings (from 28.6 % to 15 %, in beech from 30.7 % to 25.2 %).

We concluded that at sites which are prone to late spring frost the early regeneration needs protection for successful establishment, and that this protection can be provided by strip cutting along with shelterwood or on clear-cut areas by a dense ground vegetation of small shrubs.

Key words: planting, cutting types, *Fagus sylvatica, Pseudotsuga menziesii,* shrubs, gramineous, frost injuries.

Introduction

The conversion of pure and even-aged stands of Norway spruce (*Picea abies* [L.] Karst.) into mixed stands is a current silvicultural practice in Germany (Otto 1995) and other European countries (Lüpke 2004), principally due to the predicted climate change, which implies a higher intensity and frequency of extreme events and a modification of the disturbance regime of the forests. "To enhance the adaptative ability of the forests" Lüpke (2009) recommends mixed stands, because species of deviant ecological characteristics combined in one stand can extend stand stability by risk distribution (Lüpke 2004, Petercord 1999).

The mostly used species in conversion practice is beech (*Fagus sylvatica* L.), but also other broadleaved species and non-native species (e.g., Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco)) with high adaptive and productive capability should be introduced (Lüpke 2004, 2009). In order to increase the resilience potential of forests not only the choice of species but also the stand establishment technique can be a determining factor, since various regeneration methods (from shelterwood or target diameter to patch-, strip- and small scale clear-cuttings) can satisfy the different ecological demands of species (Lüpke 2009).

One apparent consequence of the climate change on forest communities in Central Europe is the lengthening of the growing season, characterized by a 2-3 week earlier start (Fabian and Menzel 1998) which can increase the risk of late frost damage (Hänninen 1991).

Late frosts represent a major constraint for the regeneration of sensitive tree species and can cause more serious problems than other physical damages when they affect sensitive parts of the plant during the growing period (Chaar and Colin 1999). They can strongly affect beech vitality, diameter growth and competitiveness, especially at high altitudes (Dittmar et al. 2006) and play a significant role in the degradation of the shape of beech and the quality of the stand (Ningre and Colin 2007), by increasing the risk of fork emergence (Ningre and Colin 2007, Kerr and Boswell 2001).

Incidence and damage potential of late frost increase with the openness of the overstorey (Langvall and Örlander 2001, Agestam et al. 2003, Thomas and Sporns 2008) and the concomitantly increasing light availability (Lundmark and Hällgren 1987, Örlander 1993, Groot and Carlson 1996, Langvall and Örlander 2001).

Whereas the protective role of shelterwoods is well known, only few studies investigated the possibility of reducing frost potential by low vegetation cover on clear cuttings. Aussenac (2000) suggested that the forest or low vegetation cover can be used to improve the microclimatic conditions (e.g., temperature) and particularly to reduce late frost damage. Although a gramineous vegetation might negatively affect the heat transfer between soil and air and thereby decrease the temperature above the soil (Larsen and Röhrig, 1978), Langvall et al. (2001) found that a *Deschampsia flexuosa* cover had no significant effect on the frequency of frost occurrence. Moreover, in this experiment neither herbicide application nor mowing of ground vegetation had any statistically significant effect on frost damage. The authors suggested that effects of field vegetation on above soil temperature depend also on vegetation cover and species composition. Referring to this, LePage and Coates (1994) showed that 70% of frost damaged spruce seedlings were located in plots where the *Rubus parviflorus* cover had been reduced. Thus, a reduction in vegetation cover can increase the hazard of frost damage for the regeneration of frost susceptible species. The beneficial effect of vegetation cover on reducing frost damage of tree regeneration is related to its height, structure and density (LePage and Coates 1994).

As to the relationship between frost damage and the size of affected saplings there are only few studies, and furthermore with contradictory results. Chaar and Colin (1999) observed that the initial seedling dimensions were not related to the intensity of frost damage, whereas Hattemer and König (1975) found for Douglas-fir seedlings that the closest correlations were those between tree height, mortality and frost damage.

In the present study the influence of different degrees of openness of the canopy of spruce shelterwood – thereafter mainly expressed as light availability - and two ground vegetation types (gramineous and small shrubs) on frost damages to young beech and Douglas-fir saplings in Central Europe was investigated. One late spring frost event gave the opportunity to observe the partial frost damages to the saplings, and to analyse the potential effects of (i) spruce shelterwood conditions and size of the plants, and (ii) the impact of ground vegetation cover.

Materials and methods

Study site

The study was carried out in the Solling Hills (Lower Saxony, Germany, 51°47’N and 9°37’E) at an altitude of about 500 m a.s.l. The site is characterized by well drained dystric cambisols (podzolic brown earths). Climate at Solling is classified as humid and sub-continental with a mean annual temperature of 6.5°C, and high mean annual values of precipitation (1,050 mm), with 470 mm during growing season. A large-scale and long-term research experiment with various logging and planting systems in pure Norway spruce stands (ca. 95 years old) was established in the autumn of 2003 by the Northwest German Forest Research Station. Three felling types (clear cutting, strip cutting and target diameter cutting) (1 ha each) were carried out in which 2-year-old European beech and 3-year-old Douglas-fir saplings were planted in the spring of 2004.

Materials and measurements

In March 2007, on each target diameter and strip cutting plot 64 beech and 64 Douglas-fir saplings, which were free of competitors like herbaceous vegetation or small shrubs, have been randomly sampled. On the clear cutting plot two vegetation types were distinguished: (1) gramineous, dominated by *Agrostis capillaries, Calamagrostis epigejos, Deschampsia flexuosa, Epilobium angustifolium, Holcus mollis, and Juncus effusus*, and (2) small shrubs, dominated by *Rubus fruticosus and Rubus idaeus.* Species were regarded as dominant when they occupied at least 75 % of the total vegetation coverage of each sample plot (a sample plot is defined as 1 m^2 circular plot around each sample seedling). In order to investigate the impact of these different vegetation types on saplings growth, 62 beech saplings of gramineous type vs. only 48 of small shrubs type, and 50 vs. 28 Douglas-fir saplings, respectively have been found and randomly sampled (Table 1). Suitable plots for the small shrubs type were scarce because both *Rubus* sp. were much less frequent.

At April 21, 2007 a late frost event was registered with an average minimum air temperature of -1.8 °C in the clear cutting plot (measured in 2 m above ground, by the Institute for Bioclimatology of the University of Göttingen with a climate station located in the plot centre; no temperature measurements were done beneath the spruce canopy).

At the beginning of June 2007 the number of sampled saplings with injuries (minimum 5 % frost damages) was counted and the proportion of damaged beech leaves and damaged new Douglas-fir needles (frost damages, %) was visually estimated. The saplings height at beginning of the vegetation period and the top height on the saplings where damages to new tissue due to frost could be seen were measured. A ground vegetation inventory was done on 1 m^2 circular plots around each sample seedling (species, cover (%), and shoot length of 5-10 individuals per species, for more details see Petritan et al. 2011). A hemispherical photo just above the uppermost leaves / needles of every sampled sapling was taken in mid-summer with a Nikon digital camera with fisheye lens and a self-levelling mount. Photos were processed with the Winscanopy software (Regents Instruments Inc., Sainte-Foy, Quebec, 2003). As a measure of light intensity, we used the total site factor (TSF) in per cent of above canopy light, which is based on 40% direct and 60% diffuse radiation, specific to our site region (Wagner 1996).

Data analysis

The probability of frost damage occurrence (as per cent of frost damaged saplings to total sampled saplings) was modelled as a function of light availability using a univariate logistic function. The models' coefficients were calculated with the maximum likelihood method, and the model analysis was based on Chi-Square test.

A linear regression analysis was used to test the relationship between the frost damaged height / frost damage (%) and height of the saplings. Only saplings with damages due to that late spring frost were included in this analysis (i.e. saplings from the clear cutting plot).

To test the effect of ground vegetation variability on the probability of frost damages occurrence and on frost damages proportion we used the analysis of variance (Two-way ANOVA), with the species (S) and competitive ground vegetation type (CVT) as factors. Normality of residuals was tested with Kolmogorov-Smirnov test and homoscedasticity with Levene test, as requirements of variance analysis. In case the two-way ANOVA yielded a significant species or competitive vegetation type effect, we examined the differences between mean values by Tukey HSD for unequal N' post-hoc test.

All data analyses were performed using Statistica 9.1 (StatSoft, Inc., USA).

Results

The checking of the sample saplings on all cutting types showed that the frost did not affect the saplings growing beneath canopy (strip and target diameter cutting), but under open field conditions (clear cutting).

The sample saplings grew under different light regimes, varying significantly from the relatively dark target diameter plot (TC) with mean TSF values of 19 % for beech and 20 % for Douglas-fir to the brighter strip cutting plot (SC) with mean TSF values of 53 % for beech and 47 % for Douglas fir, whereas in the clear cutting plot (CC) the saplings experienced the greatest TSF values: 96 % TSF for Douglas-fir and 93 % TSF (Table 1).

Table 1. General information about the sampled saplings per cutting type and species

Cutting types	Species	Target diameter Cutting	Strip Cutting	Clear Cutting
Saplings number	Beech	64	64	110
	Douglas fir	64	64	78
Height, cm	Beech	49 ± 14	76 ± 20	102 ± 26
	Douglas fir	65 ± 16	86 ± 19	141 ± 41
Light availability (TSF), %	Beech	19 ± 3	53 ± 12	93 ± 6
	Douglas fir	20 ± 2	47 ± 10	96 ± 3

Given are mean values with ± SD (standard deviation).

Our particular – fairly weak – frost event caused a significantly rising probability of frost damage occurrence with increasing light in both species (Fig. 1, Table 2), beginning at ca. 40 % TSF for beech and 75 % TSF for Douglas fir. For light availabilities less than 60 % TSF for beech and 85 % for Douglas-fir this probability is lower than 10 %. The average probability of

Table 2. Parameters of logistic model $p = e^{(a+b*x)} / (1+e^{(a+b*x)})$

Model	Species	a	b	Maximum-Likelihood Last value	- 2*log(Likelihood) of model	p (Chi-Square test)
p(TSF)	Douglas	-23.864	0.257	47.905	95.811	<0.001
	Beech	-7.753	0.087	84.368	168.737	<0.001

a, b - parameters of logistic model; p(TSF) - probability modelled as function of light (TSF); TSF - the total site factor, in per cent of above canopy light.

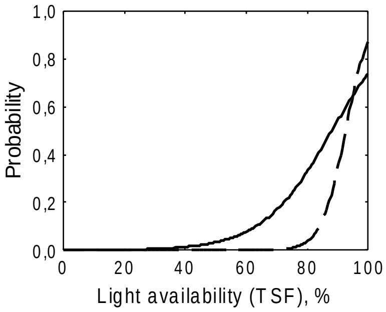

Figure 1. Probability of late spring frost damages occurrence as function of light availability (TSF, %) (The probability models are based on one frost event in April 21, 2007). Beech (solid line) and Douglas-fir (broken line)

frost damage occurrence was 0.65 for Douglas-fir saplings vs. 0.64 for beech.

In the following analyses only sample saplings of the clear cut plot were included, as frost damage occurred only on this plot. Proportion of damaged new tissue to saplings (%) was similar for both species with a slightly higher mean value for beech (18.5 %) than for Douglas-fir (17.3 %), and decreased significantly with increasing initial height in both species (Fig.2 A, B). Mean values of frost damaged height (i.e. the height above ground where the saplings exhibited damaged leaves or needles due to the late spring frost) were greater for beech (55.1 cm) than for Douglas-fir (52.3 cm). No influence of light availability on the probability of frost damage occurence and on proportion of frost damaged new tissue could be detected in both species (Fig. 2 C, D).

Impact of vegetation cover on frost damage

The vegetation inventory showed that the gramineous type had a similar coverage (in per cent of the total surface area of 1 m^2 circular plots around each sapling) with both species (46 % for beeches and 40 % for Douglas firs) and the same average shoot length, 57 cm (Table 3). The small shrubs type had a by 12 % higher coverage around Douglas-fir than around beech saplings, but with the same average shoot length of ca. 70 cm. The most dominant species within the gramineous type were *Agrostis capillaris* covering 18 % around beech and 12 % around Douglas-fir with 52 cm shoot length, and *Holcus mollis* covering ca. 16 % around both species and 59 cm long. *Deschampsia flexuosa*, *Epilobium angustifolium* and *Juncus effusus* varied from 3 to 6 % coverage. Within the small shrubs type, *Rubus idaeus* showed the same length around both species with 71 cm and a coverage of 36 % around beech vs. 30 % around Douglas fir, while *Rubus fruticosus* occupied 8 % coverage around beech (with 78 cm long) and around Douglas-fir 30 % (with 66 cm long).

The analysis of variance showed a significant effect of the coverage of each vegetation type (p<0.001,

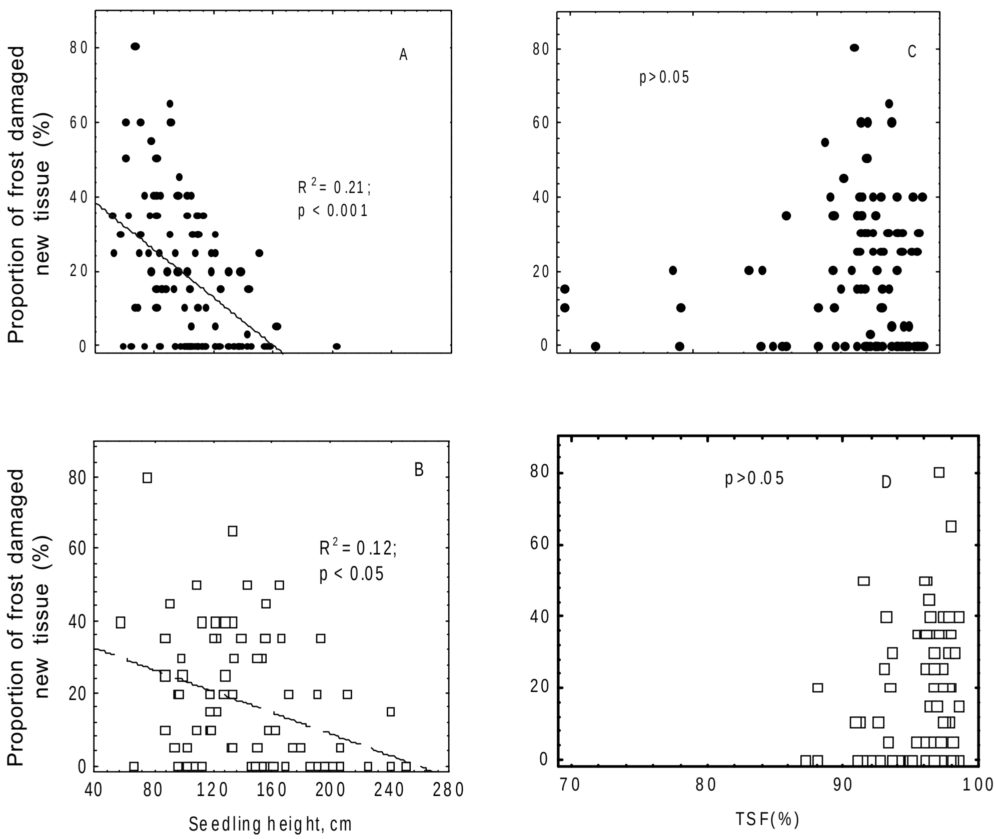

Figure 2. Proportion of frost damaged new tissue (%) in relation to seedling height (A, B) and light availability (C, D) for beech (A, C) and Douglas-fir (B, D)

Table 3. Total coverage of ground vegetation (in per cent of the total surface area of 1 m^2 circular plots around each sapling) and average shoot length

Cover vegetation type	Species	Coverage, %	Average shoot length, cm
Gramineous species	Beech	46 ± 2	58 ± 2
	Douglas-fir	40 ± 2	57 ± 2
Small shrubs species	Beech	44 ± 2	72 ± 5
	Douglas-fir	56 ± 3	69 ± 3

Given are mean values with ± SE (standard error of mean).

Fisher test, Table 4) on probability of frost damage occurence and on percentage of damaged leaves or needles, whereas for all damage parameters neither the effects of tree species nor the interactions of tree species with coverage of both vegetation types were significant (p>0.05).

Table 4. Probability of frost damage occurence (at the top) and proportion of frost damage to new tissue (below). Results of analysis of variance (Two-way ANOVA), with the species (S) and competitive vegetation type (CVT) as factors. SS: Sum of squares, MS: Mean of squares, F: Fisher test, FD: Degree of freedom

Influence of vegetation type and species on the probability of frost damage occurence					
	SS	FD	MS	F	P
Constant	57.572	1	57.572	266.871	<0.001
S	0.058	1	0.058	0.271	0.603
CVT	3.035	1	3.035	14.070	<0.001
SxCVT	0.002	1	0.002	0.013	0.909
Error	41.851	194	0.215		
Influence of vegetation type and species on the proportion of frost damaged new tissue (%)					
	SS	FD	MS	F	P
Constant	50758.14	1	50758.14	204.591	<0.001
S	775.49	1	775.49	3.125	0.079
CVT	1862.16	1	1862.16	7.506	<0.05
SxCVT	338.41	1	338.41	1.364	0.245
Error	30763.89	124	248.10		

As the vegetation cover type effect was significant, we examined the differences between mean values for the damage parameters by Tukey HSD for unequal N' post-hoc test. Significant differences between mean values of the probability of frost damage occurrence could only be detected for beech saplings (p<0.05, Fig. 3A), showing in small shrubs a probability value of 0.48 compared to 0.76 in the gramineous species. Thus, a protective effect of the small shrubs could be demonstrated as compared with gramineous vegetation. In Douglas-fir saplings, although the probability difference of 0.27 (0.45 vs. 0.72) between the two vegetation types was similar to that of beech, the effect was clearly not significant (p=0.25).

The percentage of damaged leaves or needles was independent of sapling's species (26 % in Douglas fir and 28 % in beech), but significantly influenced by the vegetation type. It decreased from gramineous to small shrubs type for both species, but significantly only in Douglas-fir saplings (Fig. 3B).

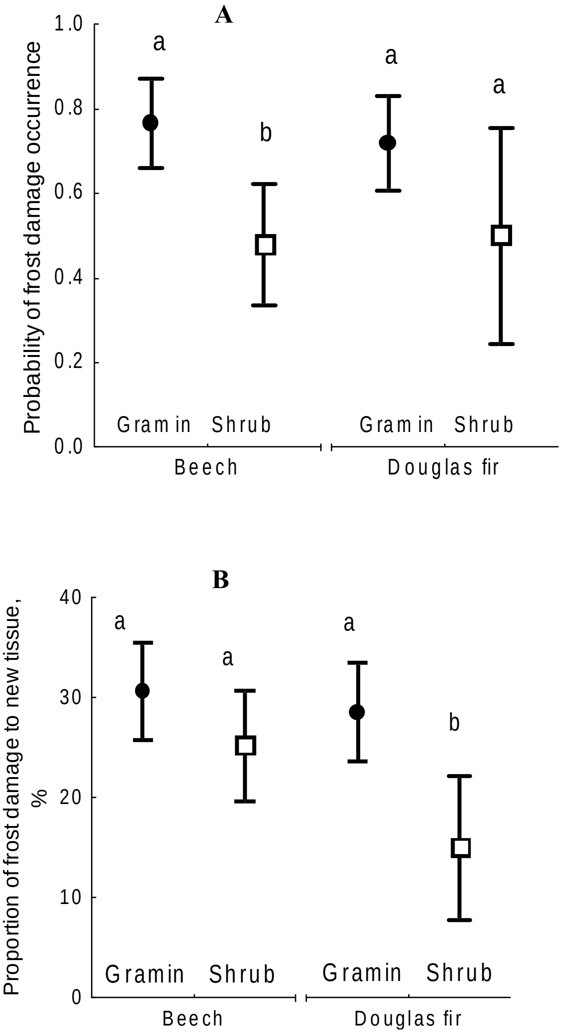

Figure 3. Relationship between tree species and vegetation type (Gramineous - Gramin, Small shrubs - Shrub) and damage parameters due to late spring frost: Probability of damage occurrence (A), and proportion of frost damaged to new tissue (B). Means and associated 95% confidence intervals are shown. Significant differences are marked by different letters (Tukey HSD for unequal N' post-hoc test, p < 0.05)

Discussion and conclusions

It is well known that an old stand canopy can protect underplanted saplings against late spring frost and potential damages out of it (Lüpke 1982, Groot and Carlson 1996, Groot 1999, Aussenac 2000, Langvall and Örlander 2001, Agestam et al. 2003). The main reasons for the reduction of frost damage risk under shelterwood as compared to open field conditions are a shorter duration of the low temperature and a higher minimum near-ground temperature in clear and calm nights due to lower emission of heat (Lüpke 1982, Örlander 1993, Groot and Carlson 1996). For example, Groot and Carlson (1996) found that average minimum temperature difference in May-June between a forest and a clear-cut opening was 3ºC, and under clear night sky conditions this difference rose to 6ºC (Groot and Carlson 1996). Similarly, Lüpke (1982) found that in clear nights the minimum temperatures at ground level on the group selection plot were 3-4ºC warmer and beneath a shelterwood plot 4-6ºC warmer than on an open plot. In both studies, underplanted saplings incurred appreciable frost damages only on open plots. Our observations are in accordance with these results as the frost in April 2007 affected only saplings on the clear cutting plot.

The use of shelter trees to prevent radiative cooling is considered to be one of the most practical methods to improve temperature conditions for the saplings (Lundmark and Hällgren 1987). To ensure sufficient protection against frost damage Langvall and Örlander (2001) found a reduction of global radiation by more than 60% under canopy compared to an open field to be sufficient which could be achieved by an overstorey density of >160 stems/ha. On our strip and target diameter cutting plots, stand density generally complied with these threshold levels (224 trees/ha and < 50 % global radiation) (Petritan et al. 2010). On our clear cutting plot the total light availability was greater than 60 % (with a mean of 94 %) which allowed frost damage occurrence in the spring of 2007. The effect of this frost event was similarly for both planted species (a similar probability of frost damage occurence of 65 % and proportion of frost damaged new tissue of ca. 27 %), that is in agreement with the previous studies about a high sensitivity to late spring frost of both species (Lüpke 1982, Thomas and Sporns 2008, Dittmar et al. 2006, Ningre and Colin 2007, Aussenac 2000). Also the negative correlation between sapling height and proportion frost damaged tissue confirms the result of Hattemer and König (1975), which showed for Douglas fir seedlings the closest correlations between tree height, mortality and frost damage. The result is in line with the known nature of late spring frosts, i.e. with temperature inversion near the ground during cloudless nights causing more damage to younger and shorter trees due to lower temperature.

The competitive vegetation type had a significant effect on the likelihood of late spring frost occurrence. Saplings growing within a dense and competitive ground vegetation of small shrubs species such as *Rubus* sp. were much less affected by our frost event. In contrast, the frost damage potential increased where gramineous competitors were present. Although the mean vegetation coverage was similar (46 % for gramineous vs. 44 % for small shrubs) beech possessed a smaller probability for the occurrence of frost damages under small shrubs competition what can be explained by a difference in average shoot length (14 cm taller small shrubs than gramineous, Table 3). Furthermore, Douglas-fir saplings were less affected by frost under small shrubs compared with gramineous vegetation as small shrubs had a greater coverage (by ca. 16 %) and shoot length (by ca. 12 cm). These results are in agreement with those of LePage and Coates (1994) who showed that reducing a *Rubus parviflorus* cover may imply an increase in frost damage. Sutton (1984) also found that frost damage increased in areas where the control of vegetation was effective. Similarly, Cole and Newton (unpublished data, from Cole et al. 1999) found that spruce were more susceptible to early winter frost damage in plots with the greatest vegetation control. Thus, an intensive vegetation management may increase the risk of frost damages at sites prone to late spring frost.

Groot (1999) found that the presence of competing vegetation on clear cuts can be used for frost protection, and that a shelterwood or strip cutting providing a maximum of 50% of above canopy light reduced frost damage risk. For species such as Douglas fir, Aussenac (2000) recommends the use of forest or low vegetation cover to improve temperature conditions, especially in relation to spring frost damage, for at least 4-5 years.

On the basis of our results and the above cited literature some conclusions can be drawn: (i) at sites with a high potential for late spring frost (e.g. level areas, hollows, bottoms of a valley), the early regeneration should be protected against frost impacts to ensure a successful establishment; (ii) this protection can be provided by strip or shelterwood cutting, or on clear-cut areas by a dense ground vegetation of small shrubs.

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ВЛИЯНИЕ ЛЕСА И НАЗЕМНОЙ РАСТИТЕЛЬНОСТИ НА ПОВРЕЖДЕНИЯ, ВЫЗВАННЫЕ ПОЗДНИМИ ВЕСЕННИМИ ЗАМОРОЗКАМИ НА САЖЕНЦЫ БУКА (*FAGUS SYLVATICA*) И ЕЛИ ДУГЛАСА (*PSEUDOTSUGA MENZIESII)*

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Резюме

Воздействие леса и двух типов низких растительных покровов (кустарников и злаковых), повреждения вызванные поздними весенними заморозками и степень повреждения были исследованы в плантациях молодого бука (*Fagus sylvatica* L.) и ели Дугласа (*Pseudotsuga menziesii* [Mirb.] Франко).

Поздние заморозки были зарегистрированы в конце апреля 2007 года, которыйе не повлияли на саженцы ниже уровня леса ели (по резке полосы или целевой диаметр режущей участков), но мороз повредил саженцы в открытом поле (на сплошной вырубки участков).

Вероятность повреждений вызваны морозом значительно увеличилось в условиях света у обоих видов, тогда как степень повреждений вызваны морозом (%, доля поврежденных листьев бука и поврежденных новые иглы ели Дугласа) уменьшается с увеличением высоты рассады для обоих видов.

Существенное влияние типа полевых растений (кустарников и травянистых) на вероятность повреждений вызваны морозом могут быть обнаружены у бука: у небольших кустарников вероятность была ниже, чем у злаковых видов (0,48 против 0,76). Степень повреждения вызвана морозом снизилась от злаковых к мелким кустарников у обоих видов, но только значительно для саженцев ели Дугласа (с 28,6% до 15%, у бука с 30,7% до 25,2%).

Мы пришли к выводу, что на участках, склонных к поздним весенним заморозкам ранняя регенерация нуждается в защите для успешного роста, и что такая защита может быть предоставлена нарезками полос вдоль леса или в районах полей плотной растительностью малых кустарников.

Ключевые слова: посадки, тип резки, *Fagus sylvatica, Pseudotsuga menziesii*, кустарники, злаковые, повреждения вызванные морозом.