GENETIC DIFFERENCES IN NEEDLE CAST DAMAGE OF SCOTS PINE (*PINUS SYLVESTRIS* L.)

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Abstract
The impact of climatic and genetic factors on needle cast damage, as well as relationship between the degree of damage and survival and growth of trees was evaluated in the study. The analysis was done in two series of experiments, both established in two locations in Latvia (central and eastern part). Needle cast damage (in 5 grade scale) as well as the height and height increment, diameter of root collar and survival of trees were assessed. Results suggest that the degree of needle cast damage was influenced by the genetic, as well as climatic factors, and also their interaction. The average degree of needle cast damage in experiment of open-pollinated families was 4.7 ± 0.01 in central and 4.6 ± 0.03 in eastern Latvia; in the experiment of control-crossed families it was 4.6 ± 0.02 in central and 3.4 ± 0.04 in eastern Latvia. The impact of genetics on the needle cast damage degree was statistically significant ($p<0.05$), and this effect was observed when any of growth traits (diameter, height or height increment) was used as a covariate in analysis. Results suggest the potential to select more resistant families, since the genetic correlation of grade of the damage between locations was significant ($r = 0.40 - 0.72$) and therefore improve also the growth of trees, since the grade of the damage had a negative correlation with growth traits both at provenance and family mean level ($r = -0.69$ and $r = -0.42$; $p<0.01$).
Key words: forest tree breeding, adaptation, genotype x environment interaction, provenance selection.

Introduction

Global climate change is predicted not only to increase the duration of the growing season, but also the sum of active temperatures and number of warm days (when the average air temperature is above +5 °C) and to alter the precipitation regime. These changes will affect growth of the trees (Jansons *et al*., 2013a) and the effect might be different for different tree species (Jansons *et al*., 2013b, 2014a, 2015a; Augustaitis *et al*., 2015; Šēnhofa *et al*., 2016), as well as for provenance within a tree species (Rieksts-Riekstiņš *et al*., 2014). Meteorological factors limiting growth are also changing as the climate changes (Jansons *et al*., 2015c). Climate change will affect tree growth not only directly but also indirectly: by determination of the presence and vigour of various species of fungi, which in turn will affect the survival and growth of the trees, depending on their resistance against a particular pathogen.

One of the most important group of needle pathogens of Scots pine (*Pinus sylvestris* L.) in nurseries and young stands (up to 24 years) are *Lophodermium spp*. fungi (Drenkhan, 2011), mostly *Lophodermium seditiosum* (Minter, Staley, & Millar), which in the territory of Latvia is characterized by a high genetic diversity (Moročko-Bičevska *et al*., 2010) and a one-year development cycle (Ortiz-García *et al*., 2003). Researches in Estonia have found that epidemics of *Lophodermium spp*. are largely determined by the sum of precipitation from May till August in the previous year, while the average air temperature in summer (except August) had no significant impact on the spread of the infection (Drenkhan, 2011). Favourable weather conditions for this disease have been observed in recent years – humid and warm autumn (as well as the end of summer) and mild winters (Martinsson, 1979; Stenström & Arvidsson, 2001). In recent years, in Latvia other diseases significantly affecting needles have been identified, too: *Diplodia pinea* (Desmo.) J. Kickx and *Dothistroma septosporum* (Adamson *et al*., 2015). Tree breeding (and use of selected material in forest regeneration) can have an important role in the reduction of *Lophodermium spp*. and other needle cast diseases, since it is well developed and financially viable activity in Latvia (Gailis, & Jansons, 2010; Jansons *et al*., 2011, 2015b) with proven effect on quantitative traits of Scots pine (Jansons, 2005, 2008; Jansons *et al*., 2006). Therefore, the existing basis of experimental trials and infrastructure as well as platform for propagation (seed orchard) can be used to improve the resistance of needle cast simultaneously with other traits. Earlier studies have indicated the potential role of genetics in resistance to the needle cast (Liesebach & Stephan, 1996), but this effect may vary between the populations within a species. Therefore, the aim of the study was to assess the damage of the needle cast in climatically different planting locations in Latvia and influence of the pine genetics on it.

Materials and Methods

Assessment of damages caused by needle cast for Scots pine was carried out in 2 series of experiments located in the Scots pine forests and bordering the Scots pine stands (at least on one side), therefore with a possibility of the needle cast infection. The first series consisted of an experiment of Scots pine open-pollinated families (hereinafter – open-pollinated experiment) altogether 226 (the average number of families from one provenance – 18), established in the central (57°00'N, 23°10'E) and eastern (56°40'N, 25°58'E) parts of Latvia. The second series consisted of a control-crossed trial (hereinafter – control-crossed experiment), established in the central (56°41'N, 24°26'E) and eastern (56°40'N, 25°58'E) parts of Latvia. This experiment involved 10 clones, crossed by diallel scheme; taking into account that not all crossings had been successful, in both sites 72 families were located. These families were divided into 5 groups: Group 1 – crossings between Ugale clones, Group 2 – crossings between Kalsnava clones, Group 3 – crossings between Ugale and Kalsnava clones, Group 4 – open-pollinated families of Ugale clones, Group 5 – open-pollinated families of Kalsnava clones. Needle cast damage in the first series was assessed during the second growing season, in the second – during the sixth. In both series evaluation was done visually in 5 grade scale, depending on the proportion of damaged (brown) one-year old needles: 1st grade – 0-5%; 2nd grade – 6-35%; 3rd grade – 36-65%; 4th grade – 66-95% and 5th grade – 96-100%. Additionally, in the second series the tree height and diameter (at root collar), as well as the height increment in the third, fourth and fifth growing season was measured. Single factor and two-factor analysis of variance and correlation analysis were used to evaluate the influence of various factors on analysed traits and relationships between these traits.

Results and Discussion

In both experiments (open-pollinated and control-crossed) pines were notably affected by the needle cast infection. The average grade of the needle cast damage in open-pollinated trail in central Latvia was 4.7 ± 0.01 and in eastern: 4.6 ± 0.03, but in both location of control-crossed experiment 4.6 ± 0.02 and 3.4 ± 0.04, respectively. In both series of experiments statistically significant ($p<0.001$) impact on the planting site of the needle cast damage grade was found. It conforms to the results of other studies (Martinsson, 1979). In both series lower grade of the needle cast damage was observed in plantations in the eastern Latvia, where characterised by higher continentality and the increasing daily temperature range (Draveniece, 2007). Such differences over a long period of time had led to evolutionary adaptation of the Scots pine: provenance from the western part of the country when planted in the eastern part was unable to achieve the same average height and diameter as “local” provenances (Jansons, Baumanis, 2005). Such results were consistent across numerous provenances and progeny plantations, therefore 2 provenance regions had been established in Latvia – Western and Eastern (26 March 2013 CM Regulations No. 159 ‘Regulations on forest reproductive material’). Since the sites in both series of trials are located in different provenance regions, it is possible that climatic differences have largely influenced the results – observed differences in grade of the needle cast damage between the sites.

Long-term meteorological data for the period from 1961 to 2010 demonstrated that in August, when the infection of *Lophodermium* is spread and significant impact of weather conditions on the occurrence of the disease is observed (Drenkhan, 2011), the average daily temperature in the eastern part of Latvia was significantly lower than in the central part (Fig. 1). In the previous year (before the needle cast damage assessment), the average daily temperature in August in the eastern part of Latvia was lower than in other locations. A higher sum of precipitations was

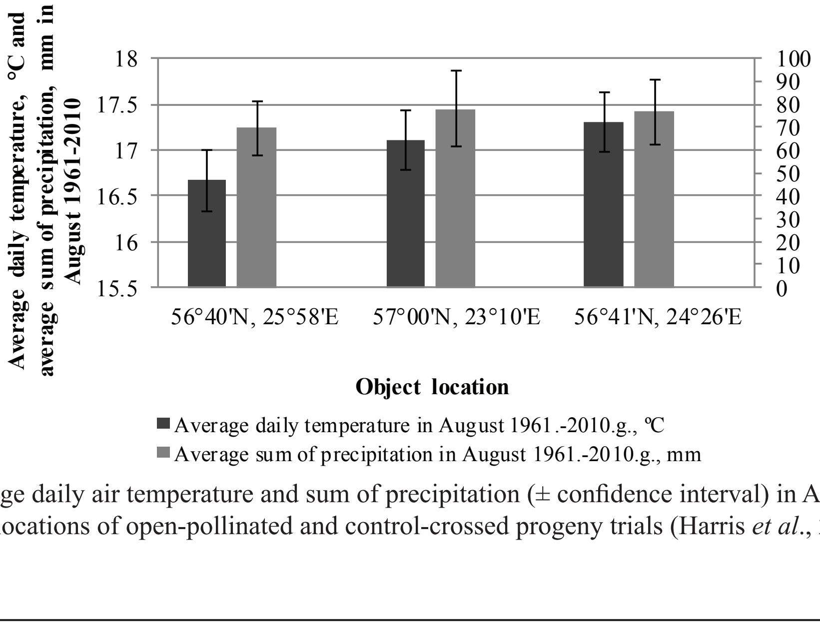

Figure 1. Average daily air temperature and sum of precipitation (± confidence interval) in August 1961 – 2010 in locations of open-pollinated and control-crossed progeny trials (Harris *et al*., 2014).

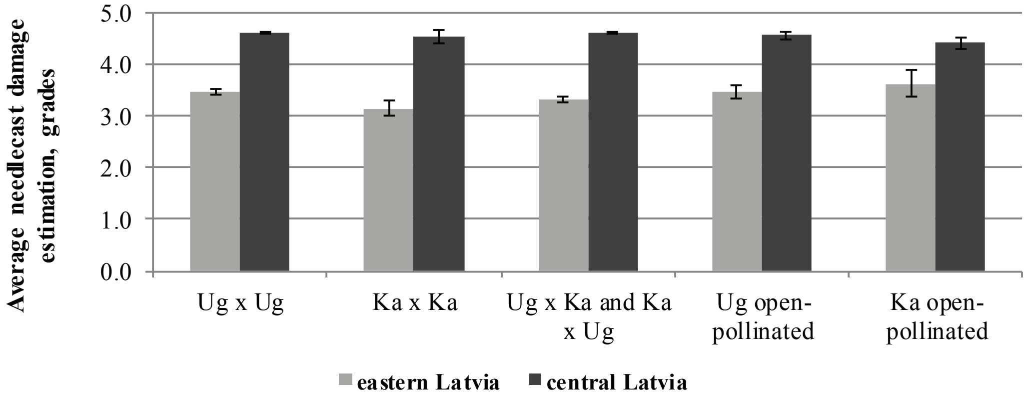

Figure 2. Estimation of needle cast damage (± confidence interval) of different groups in a control-crossed progeny trial in two locations.
Ug x Ug – crossings between Ugale clones; Ka x Ka – crossings between Kalsnava clones;
Ug x Ka un Ka x Ug – crossings between Ugale and Kalsnava clones;
Ug – open-pollinated families of Ugale clones; Ka – open-pollinated families of Kalsnava clones.

observed in location in the central part of Latvia, which also contributes to the spreading of the needle cast (Drenkhan, 2011). In the year prior to the needle cast damage, differences were not observed during the assessment of rainfall, however, the meteorological stations were located in the distance of 10 – 20 km from the experimental sites, therefore the more accurate information about precipitation (which may vary locally) is lacking.

In both series of experiments, the level (grade) of the needle cast damage was largely determined by genetics: both open-pollinated and control-crossed family had a statistically significant ($p<0.001$) impact on the degree of the needle cast damage. In both open-pollinated progeny trials a statistically significant impact of provenance was observed, too: in the eastern part of Latvia $p<0.05$, provenance average grade of the needle cast damage ranged from 4.33 to 4.72; in the central part of Latvia $p<0.001$, provenance average grade of the needle cast damage ranged from 4.51 to 4.78. In a similar study with a smaller set of material (60 open-pollinated families, representing 5 provenances) a significant provenance impact on damages of the needle cast disease at the fourth growing season was not found, but in a study with a larger set of material (207 families from seven provenances) – a significant impact was found during the third growing season (Jansons, Neimane, & Baumanis, 2008). Similarly, other studies have found significant differences of resistance to the needle cast between provenances from the same or different countries (Squillace *et al.*, 1975; Stephan & Scholz, 1981; Бауманис, 1983; Ostry & Nicholls, 1989; Vuorinen, 2008). In our study, similar to the impact of provenance, the group in the control-crossed experiment also had a statistically significant impact on the needle cast damage grade, ranging from 3.15 to 3.64 in the eastern part of Latvia and from 4.42 to 4.62 in the central part of the country (Fig. 2).

In our study, in both series of experiments a statistically significant ($p<0.001$) correlation between the degree of needle cast damage in different locations was found: in the control-crossed experiments Pearson correlation coefficient $r = 0.72$; in open-pollinated $r = 0.40$. A tighter correlation in the control-crossed experiment can be explained by higher genetic homogeneity in comparison to open-pollinated families. In both series significant genetics x location interaction was observed, too i.e. some families had a high mean grade of the needle cast damage only in one of the locations.

Analysis of a single-tree data in the open-pollinated progeny trials revealed a significant ($p<0.001$) interaction effect between the planting site (location) and provenance, as well as between the planting site and family. Descendants of many provenances had a relatively stable (similar) grade of the needle cast damage in both locations, e.g. Tukums, Dundaga, Ugales and Lubanas provenances were characterized by relatively low, but Bauska and Jaunjelgavas provenances – high grade of the needle cast damage; however, certain provenances had a notably different grade of the needle cast damage between locations e.g. Kalsnava. Still, it should be noted, that the degree of the needle cast damage was generally high and varied in relatively small range. Analysis of a single-tree data in control-crossed experiment revealed a significant ($p<0.001$) interaction between the plantation site (location) and crossing (family), and between the location and the group of crossings. Most of the groups of controlled crossings kept grade of the needle cast damage relatively stable in both locations, e.g. crosses between Kalsnava clones had a relatively low degree of the needle cast damage in both sites.

In our study, on the whole, no differences in grade of the needle cast damage related to the adaptation to a particular growth area (provenance region) were found (i.e. it was not found that in the western provenance region pines from this region would have a lower grade of the needle cast damage than pines from the eastern region, or vice versa), while the particular provenance (and family) significantly influences the resistance to the needle cast. Some earlier studies conformed the effects of genotype and environment interaction on resistance to needle cast (Baumanis, 1975; Millar, 1975; Martinsson, 1979), but others – rejected it (Squillace *et al.*, 1975).

Relationship between the degree of the needle cast damage with survival and growth was assessed in our study. The correlation between the degree of the needle cast damage and survival in a series of open-pollinated progeny trial was negative and statistically significant – both at provenance and family mean level (r = -0.69 and r = -0.42; p<0.01). Similarly, Jansons *et al.* (2008) found that the grade of the needle damage had a significant impact on the survival in open-pollinated families at the age of 3 years. In the control-crossed experiment during our study the degree of the needle cast damage statistically significantly correlated with tree growth parameters, both at the individual tree and family (controlled crossing) level. The tightest negative Pearson correlation coefficients were found between the degree of needle cast damage and stem diameter at a root collar at the age of 5 years (p<0.001; at the individual tree level in the eastern and central Latvia r = -0.29 and r = -0.38, at family mean level: r = -0.48 and r = -0.69, respectively), as well as between the grade of the needle cast damage and the height increment of the year before the assessment (p < 0.001; at the individual tree level in the eastern and central Latvia r = -0.28 and r = -0.31, at family mean level: r = -0.59 in both locations (Fig. 3). In other studies, a significant negative correlation between the degree of the needle cast damage and tree growth parameters have been found, too (Baumanis, 1975; Squillace *et al*., 1975; Martinsson, 1979; Ostry & Nicholls, 1989).

In our study, values of Pearson correlation coefficient (between growth traits and needle cast damage grade) of the control-crossed families were higher than those of individual trees, suggesting significant influence of genetics – slower growing families were characterized by lower resistance to the needle cast infection, possibly because they had already suffered from it before the assessment, resulting in a decreased height growth. Similarly, Jansons *et al*. (2008) found that the degree of the needle cast damage not only had a significant (p<0.001) impact on the height increment of trees in a current year, but also a higher degree of the needle cast damage was found for the trees that were relatively smaller in the

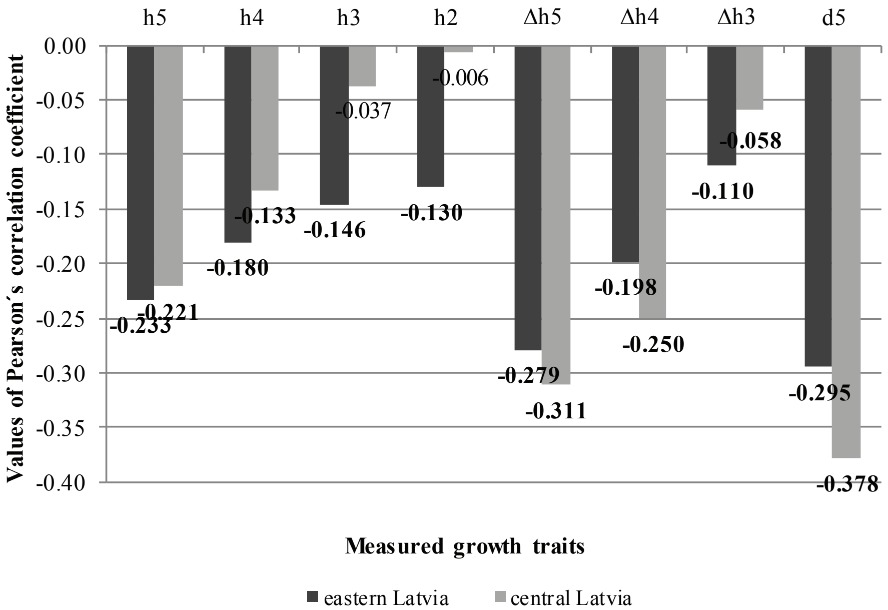

Figure 3. Comparison of values of Pearson´s correlation coefficient depending on the degree of needle cast damage and growth traits at individual tree level in control-crossed experiment.
h5 – height of trees at age of 5 years; h4 – height of trees at age of 4 years;
h3 – height of trees at age of 3 years; h2 – height of trees at age of 2 years
Δh5 – height increment of trees in the 5thgrowing season;
Δh4 – height increment of trees in the 4thgrowing season,
Δh3 – height increment of trees in the 3rdgrowing season; d5 – root collar diameter of trees at age of 5 years
Significant values marked in bold.

year prior to the needle cast damages. Other authors have pointed out that provenances resistant against the needle cast were characterised also by higher productivity (Liesebach & Stephan, 1998).

Analysis of the grade of the needle cast damage in the control-crossed experiment where growth traits (height, height increment, root collar diameter) were used as covariates (thus excluding their impact) still resulted in a statistically significant ($p<0.01$) impact of family and group of crossings. This result confirms that the degree of the needle cast damage is not only linked to the tree growth, but is also directly affected by genetics of trees.

Conclusions

1. The grade of the needle cast damage in open-pollinated and control-crossed experiment was statistically significantly ($p<0.001$) affected by the location. In both series of experiments the grade of the needle cast damage was lower in locations with a higher average daily temperature in August.
2. The grade of the needle cast damage in all locations was statistically significantly ($p<0.05$) influenced by genetics (family of trees), as well as the group of controlled crosses (in control-crossed experiment) or provenance (in open-pollinated experiment); significant impact of interaction between the tree genetics and the planting site (location) was found, too, suggesting a local adaptation of separate families (provenances).
3. Genetically more uniform material (controlled crosses) had stronger correlation between the grade of the needle cast damage and locations than less homogenous material (open-pollinated progenies): $r = 0.72$ and $r = 0.40$, respectively.
4. The correlation between the degree of the needle cast damage and tree survival at family and provenance level, as well as between the degree of the needle cast damage and growth traits (height, height increment and root collar diameter) was significant.
5. Study confirms that heredity has a significant impact on the intensity of damage.

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