Lesn. Cas. For. J. 60 (2014) 60–66

PÔVODNÁ PRÁCA – ORIGINAL PAPER

Lesnícky časopis - Forestry Journal
http://www.nlcsk.sk/fj/

Impact of irrigation on the gallery parameters of spruce bark beetle (*Ips typographus* L., Coleoptera: Curculionidae, Scolytinae)

Vplyv zavlažovania na parametre požerkov lykožrúta smrekového (*Ips typographus* L., Coleoptera: Curculionidae, Scolytinae)

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Abstract
In the spruce stand situated in Central Slovakia, a manipulation experiment was performed aimed at attracting spruce bark beetle (*Ips typographus*) to living and healthy spruce trees using pheromone dispensers. The goal of the experiment was to show that the galleries of the *Ips typographus* in the irrigated spruce trees differed in the parameters from the galleries in drought-stressed trees. Significant differences were revealed mainly in those gallery parameters that occur after the excavation of a nuptial chamber, or after the mating of parental beetles. The revealed differences prove that drought in combination with extreme temperatures significantly reduces defence reactions of spruce against the attack of *Ips typographus*. Water deficit together with high temperatures significantly postpone and retard the activation of defence reactions of spruce on one side, and accelerates the regeneration and the development of *Ips typographus* on the other side.
Keywords: *Ips typographus;* bark beetles; *Picea abies;* water stress; drought

Abstrakt
V smrekovom poraste stredného Slovenska bol realizovaný manipulovaný experiment s lákaním lykožrúta smrekového (*Ips typographus*) pomocou feromónových odparníkov na živé a zdravé smreky. Cieľom experimentu bolo preukázať, že zavlažované smreky budú vykazovať odlišné hodnoty parametrov požerkov lykožrúta smrekového v porovnaní so suchom stresovanými smrekmi. Štatisticky významné rozdiely boli zistené predovšetkým v parametroch požerkov, ktoré vznikajú po vytvorení snubnej komôrky, resp. po párení rodičovských chrobákov. Preukázané rozdiely dokazujú, že sucho v kombinácii s extrémnymi teplotami významne oslabuje obranné reakcie smreka voči ataku lykožrúta smrekového. Vodný deficit v spojitosti s vysokými teplotami na jednej strane významne oneskoruje a spomaľuje aktivizáciu obranných reakcii smreka a na strane druhej urýchľuje rozmnožovanie a vývoj lykožrúta smrekového.
Kľúčové slová: *Ips typographus;* podkôrny hmyz; *Picea abies*; vodný stres; sucho

1. Introduction

European spruce bark beetle (*Ips typographus* L., Coleoptera: Curculionidae, Scolytinae) belongs to one of the most important insect pests of mountainous forests at European level (Lieutier et al. 2004). In the last 6 years, this bark beetle has been the most destructive disturbance agent in Slovak forests; in 2012, 1.9 mil. m^3 of processed spruce timber was infected by spruce bark beetle (Kunca et al. 2013) and a similar amount is estimated for 2013. During the last gradation of spruce bark beetle that has lasted since 2003, 19 mil. m^3 of timber have been damaged, which makes this gradation the largest in the forestry history of Slovakia (Vakula et al. 2013). The outbreaks of spruce bark beetle have been initiated by windthrows in the mountains of the Central Carpathians (High Tatras, Low Tatras) and physiological weakening of spruce stands in the mountain ranges formed by flysch rocks (Kysuce and Orava Beskids, Spišská Magura). Physiological weakening of spruce stands or so called contemporary spruce decline (Turčáni et al. 2006) is accompanied by the activation of Honey fungus (*Armillaria* spp.), which attacks living trees. The trees are consequently attacked by bark beetles. This type of spruce forest dieback occurs also in the border regions of the Czech Republic and Poland (Holuša 2004; Grodzki 2007).

Frequent occurrence of rainless periods with extreme temperatures is one of the significant factors causing this type of dieback, as such periods result in the lack of soil water causing water stress. Minďáš et al. (2000) consider the lack of precipitation and high evapotranspiration to be an important stress factor at sites below 1,000 m above sea level. Drought can occur not only on typical dry sites, but also on sites considered as moist. Spruce is a tree species with a shallow root system, and the water shortage during the periods with short-term decrease of ground water will be more apparent on moist sites than on permanently dry sites (Worell 1983).

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Forest stands that are insufficiently adapted to current changed environmental conditions, such as secondary Norway spruce stands (*Picea abies*) growing outside their natural occurrence, are particularly susceptible to disturbances (Seidl et al. 2008).

Water stress is in general considered as one of the predisposing factors causing bark beetle outbreak. However, this view is often based on random observations of the connections between dry weather and bark beetle outbreaks. Although the relationship between drought and bark beetles is known, the performed experiments are rare and often contradictory (Christiansen & Bakke 1997). Warm and dry weather can increase the frequency of bark beetles in two different ways: directly – drought affects physiological conditions of trees and makes them susceptible to bark beetle attack, indirectly – high temperatures create favourable conditions for mass bark beetle swarming, and for their searching for host trees, and accelerate the juvenile development. Christiansen & Bakke (1997) found that except for scarce cases of long-term droughts, it is more probable that the dynamics of bark beetle propagation is directly affected by spring weather rather than indirectly by the physiology of host tree species. The analysis of long-term data from the south-eastern Alps showed that spring drought increases the next-year damage caused by bark beetle, while warm spring affects its phenology (Faccoli 2009). Monitoring of bark beetle development in relation to temperature is problematic because of high variability of microclimatic conditions under bark. Above all, the impact of solar radiation can cause the differences in the temperature measured under bark when compared with the surrounding air temperature. Due to this, the data from field experiments have greater variability than those from laboratory experiments. Öhrn (2012) compared the results of laboratory and field experiments of different developmental stages of spruce bark beetle. He came to the conclusion that the sum of cumulative air temperatures under field conditions equals less than 75% of the sum of cumulative temperatures measured in laboratory conditions. The difference between the cumulative temperatures measured under bark and those measured in the air increases with the sunshine amount during the season (Coeln et al. 1996). In Russia, drought is considered one of the main causes of the occurrence of bark beetle outbreak. Drought usually occurs after a winter characterised by strong frost and temperatures below –40 °C. These conditions when combined with low snow cover of 10–15 cm and its rapid springtime melt and runoff, result in drought (Skuhravý 2002). Grodzki et al. (2006) consider natural factors, such as aspect, site characteristics, and weather to be crucial for the development of bark beetle outbreak in old spruce stands. Most of the published experiments dealing with drought and bark beetle come from the northern America and describe the susceptibility of *Pinus taeda* to the attack of *Dendroctonus frontalis* (Lieutier et al. 2004).

The goal of this experiment was to confirm the hypothesis that during the rainless period, the gallery parameters of *Ips typographus* in irrigated spruce trees are different from those in non-irrigated trees.

2. Material and methods

In 2012, two groups of trees were selected in a spruce stand, one irrigated and one non-irrigated (so called control) group, each consisting of 6 individuals. During the drought period, a manipulated experiment with *Ips typographus* was performed on the two groups. Three types of data were collected on the research plot: i/ gallery parameters of *Ips typographus*, ii/ meteorological data, and iii/ soil moisture characteristics.

2.1. Study plot

The experimental plot is situated in Central Slovakia near the settlement of Hriňová (48°35´53´´N; 19°31´52´´E). Orographically, this region belongs to the Poľana mountain range of volcanic origin. Geologically, the plot is located at the transition between the crystalline rocks (granodiorites) and volcanic rocks (andesite tuffs). Soil is classified as Eutric Cambisol (according to WRB; FAO 2006), has favourable physical characteristics and low proportion of gravel. Spruce stand No. 283-20 was planted 28 years ago. The aspect is south--eastern, slope is 5% and elevation is 670 m above sea level. Mean tree height is 18m, and mean diameter at breast height $d_{1.30}$ is 21cm. In spite of the low age, spruce trees growing on the fertile sites have the dimensions that are suitable for the development of *Ips typographus*. In 2009, the trees on the research plots were pruned up to 3 m height. The plot is located in a moderately cool region with mean annual temperature of 6.2 °C and mean annual precipitation totals of 768 mm. In 2009–2010, the impact of soil drought on mensuration characteristics (Blaženec et al. 2011) and physiological processes of spruce (Kurjak et al. 2012) was studied.

2.2. Irrigation, meteorological measurements, measurements of soil characteristics

For the irrigation of the experimental plot, we used two plastic containers with the total volume of 2,000 l. Water was distributed to individual trees using plastic tubes with a diameter of 16 mm. Root irrigation was applied using two circles of perforated pipes situated 50 and 100 cm from the stem. The irrigation was applied during drought periods before the experiment (4 times) and during the experiment (5 times). Altogether, 2,970 l of water (9 × 330 l) was applied per one tree in the irrigated plot, which equals approximately 30 mm of precipitation per one application of irrigation. The trees in the control group were not irrigated.

Meteorological measurements were performed at a nearby open space at an elevation of 750 m a.s.l. using a digital meteorological station EMS Brno (CZ), in correspondence with the methodology of the international program ICP Forests. Global radiation was measured with Minikin RT sensor ($W.m^{-2}$), air temperature and humidity were measured with the integrated sensor Minikin TH (in °C and %, respectively) at a height of 2 m above ground. Meteorological data were re-measured and stored every hour. Precipitation totals were recorded at each precipitation event with an automatic rain-gauge with a catch area of 320 cm^2 and 0.2 mm resolution (MetOne 370, Oregon, USA).

Directly in the experimental stand, two standard soil moisture characteristics were continuously measured: soil water content (SWC) in volumetric % and soil water potential (SWP) in pressure units (bar or MPa). Soil water potential was directly measured at six points in the stand (3 points in the irrigated and 3 points in the control plot), always in three different depths (15, 30, and 50 cm). The measurements were realised using gypsum blocks (GB1, Delmhorst Instrument, NJ, USA), while hourly data were recorded in individual dataloggers of MicroLog SP3 type (EMS Brno, CZ). The sensors used for the measurement of soil water potential can measure the values in a limited range from 0 to 11 bars, and work using the principle: "the more intensive the soil drought is, the less available is the water in soil, and greater pressure is needed to extract it". Maximum value of suction pressure equal to 11 bars indicates that soil water is practically unavailable for a tree. Volumetric soil moisture was measured with EC10 sensors (Decagon Devices, Ing., USA) in the same design as SWP, i.e. at six points in the stand and two depths (15 and 50 cm). Data were recorded every hour and stored in two-channel MicroLog V2 dataloggers (EMS Brno, CZ). This soil moisture characteristic was only an auxiliary indicator used for the documentation of the seasonal dynamics of soil water content. Without continuous sensor calibration to specific conditions at the particular site, absolute values of SWC are questionable due to the technological limits of the sensors, as they show systematically low values, particularly during soil drought. Previous research studies (Sitková et al. 2011), which included sensor calibration and data correction on the base of the results of parallel gravimetric measurements, showed underestimation of volumetric soil moisture measured with the sensors of EC-10 type.

All data were processed for two time periods: for the growing season of 2012 (from April 1st to September 30th) and for the period of the manipulated experiment (from June 29th to July 4th, 2012).

2.3. Manipulated experiment with *Ips typographus*

The manipulated experiment was realised during the summer swarming of bark beetle, from June 29th, 2012 to July 4th, 2012 (5 days). On June 29th, 2012, one IT Ecolure Tubus pheromone dispenser (Fytofarm, s. r. o.) was installed on each tree at breast height, which attracted *Ips typographus* and caused its mass attack on the trees. On the third day after the installation of the dispensers (i.e. on July 2nd, 2012), the trees were infested and IT Ecolure Tubus dispensers were replaced with IT Ecorep repellents (Fytofarm, s. r. o.). On the fourth and fifth day (i.e. on July 3rd and 4th, 2012), we assessed the following gallery parameters: number of entrance holes on the trees, level of resin production (sealing of entrance holes), size of nuptial chambers, number of parental adults in the galleries, number of maternal galleries, length of maternal tunnels, and number of eggs per one maternal gallery. Altogether, 148 galleries were assessed on 12 trees.

The number of entrance holes was counted on tree stems up to the height of 260 cm. The entrance holes were identified by the boring dust extruded from the hole. On the fourth day of the experiment, every identified entrance hole was marked with the colour pin. The gallery parameters were analysed around the pheromone dispenser ($d_{1.30}$) inside the 297 mm wide stripe after the places around the entrance holes had been debarked (Fig. 1a). If we did not find the sufficient number of entrance holes within the stripe, we also analysed outer galleries located close to the stripe.

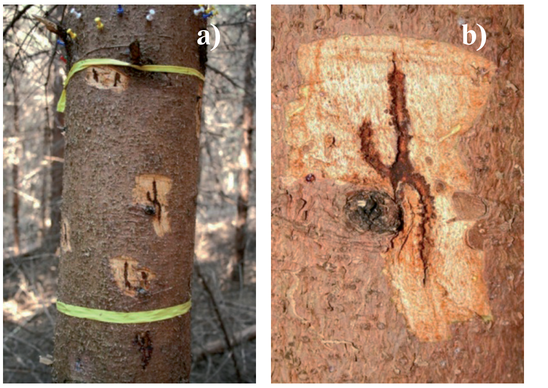

Fig. 1. Uncovered galleries of *Ips typographus* on the experimental tree a); Resin was not present in the galleries even on the third experiment day b).

The level of resin production was assessed after the gallery had been uncovered with a knife. We used five-level classification according to the amount of the resin flowing into the gallery: 0 – no production, 1 – low production, 2 – moderate production, 3 – intense production, 4 – extreme production.

The area of the nuptial chamber (mm^2) was calculated from its width and length. After the whole gallery had been uncovered, we assessed the number of parental adults (pieces), number of maternal tunnels (pieces), length of maternal tunnels (mm) and number of laid eggs per one maternal tunnel (pieces). We alternately analysed one tree from the irrigated plot and one tree from the control plot to ensure the comparability of the results.

Statistical evaluation of the results was performed with Statistica 10 software (Stat Soft, CR, s. r. o.), and included single-factor ANOVA and Pearson χ^2 test (the values were logarithmically transformed).

3. Results and discussion

3.2. Development of meteorological situation in the 2012 season

Long-term average temperature of the growing season (April to September) at Hriňová site calculated from the period 1961–1990 is 12.5 °C (Table 1). Hence, from this point, the growing season of 2012 characterised with the mean air temperature of 14.7 °C can be considered as above-average. All months of the growing season exceeded their long-term average from 1.5 °C in April up to 2.7 °C in August. From the point of precipitation, the growing season of 2012 with its precipitation totals of 413.2 mm was slightly deficient in comparison with the long-term average (459 mm). Except for July, when the monthly precipitation equalled 222 % (RR%) of the long-term average of 1961–1990, monthly precipitation totals of other months of the growing season were below average. August with its precipitation total of 14.8 mm (RR% =

19.6%) was the driest month, and May was the second driest (RR% = 49.9 %). Daily average global radiation in the 2012 season was 191.4 W.m^{-2}, and daily average air humidity was 74.7%. Soil moisture dynamics naturally reflects the seasonal course of precipitation. During the artificial irrigation, soil moisture of the irrigated group of trees increased when compared with the control group. This is documented by the significant reduction of soil water potential (pressure) in the irrigated part during the inoculation experiment (Table 1, Fig. 2).

During the experiment (i.e. from June 29th to July 4th), daily mean air temperature fluctuated between 18.7 and 24.9 °C, and daily maximum temperatures were from 24.4 °C to 30.0 °C. The weather was hot and without any precipitation during the whole period of the experiment. The first precipitation with the total volume of 9 mm was recorded just before the end of the experiment, on July 4th, 2012 in the afternoon. Daily average global radiation was the highest on the 4th day of the experiment (i.e. on July 2nd), when it reached the value of 294 W.m^{-2}. Daily average air humidity during the experiment was 69%.

3.2. Manipulated experiment

All trees were infested by European spruce bark on the third day after luring. The parameters of the infestation and of individual galleries are given in Table 2.

No significant difference in the density of entrance holes up to the stem height of 260 cm was found between the irrigated and control plots (ANOVA, $F_{(1;10)} = 0.005$, $P = 0.948$). Great aggregation ability of the pheromone dispenser equally affected both the irrigated and control trees. This is proved by an almost equal number of entrance holes on both the irrigated (32.2 ± 13.6 of entrance holes per tree, or 0.21 ± 0.07 of an entrance hole per 1 dm^2) and control (33.2 ± 17.5 of entrance holes per tree, or 0.22 ± 0.12 of an entrance hole per 1 dm^2) trees. Similarly, Turčáni & Nakládal (2007) did not find any significant differences in the boring frequency and intensity of *Ips typographus* males between more and less drought-stressed spruce trees during warm and sunny weather.

In our case, all entrance holes occurred up to the height of 260 cm, i.e. in a distance of 130 cm from the pheromone dispenser. Mulock & Christiansen (1986) present the maximum number of entrance holes up to the height of 300 cm from tree foot, when the dispenser was located at breast height ($d_{1.30}$), however, they analysed adult trees.

Apart from the trees on the experimental plot, 3 neighbouring trees were also slightly infested (4 entrance holes). The number of entrance holes increased towards the pheromone dispenser. Although the infestation density close to the pheromone dispenser was equal to 0.5 entrance holes per 1 dm^2, all trees were able to withstand the attack of bark beetles. Their reactions to infestation in the form of the increased production of resin were delayed both on the irrigated and control plots. During similar experiments in 30-year old stands we observed flushing of galleries by resin already in the stage of the creation of nuptial chambers (Vakula pers. observ.). On the studied experimental plot, no tree mortality occurred in spite of the delayed reactions, which means that the threshold of successful attack was not reached. If the threshold of successful attack is exceeded, local population of a pest has a tendency to reach the epidemic level, which can result in the mortality of healthy trees (Thalenhors 1958; Berryma 1978).

Up to 3rd day after the tree infestation by *Ips typographus*, almost no reaction of trees in the form of resin production in

Table 1. Statistical characteristics of the daily data of meteorological parameters in the 2012 growing season (i.e. from April 1st to September 30th, 2012) and during the manipulated experiment (i.e. from June 29th to July 4th, 2012).

	Growing season 1. 4. – 30. 9.				Manipulated experiment 29. 6. – 4. 7.			
	$x \pm s_x$	Min	Max	s_x %	$x \pm s_x$	Min	Max	s_x %
Air temperature [°C]	14.7 ± 5.4	-0.9	24.9	36.7	22.6 ± 2.8	18.7	24.9	12.4
Air humidity [%]	74.7 ± 13.8	38.8	100	18.5	68.9 ± 9.7	56.9	80.5	14.1
Global radiation [W.m^{-2}]	191.4 ± 70.2	22.2	319.6	36.7	251.8 ± 58.5	136.3	293.9	23.2
Soil water content –SWC [%] contr	9.8 ± 2.6	5.6	16.9	26.5	7.5 ± 0.3	7.1	7.7	4.0
Soil water content –SWC [%] irrig	10.9 ± 3.0	6.7	16.8	27.5	14.8 ± 1.5	13.4	16.8	10.1
Soil water potential – SWP [bar] contr	7.6 ± 3.7	1.0	11.0	48.7	11.0 ± 0.0	11.0	11.0	0.0
Soil water potential – SWP [bar] irrig	6.8 ± 3.6	0.5	11.0	52.9	3.3 ± 0.4	2.7	3.8	12.1

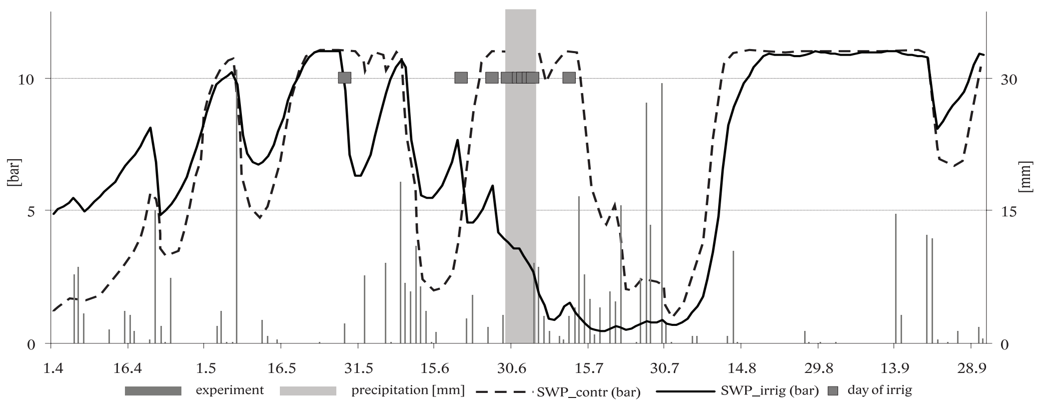

Fig. 2. Course of daily precipitation totals [mm], daily average values of soil water potential SWP [bar] in the irrigated plot (irrig) and control plot (contr) during the growing season of 2012. Grey colour indicates the period of the manipulated experiment.

Table 2. Average number of entrance holes and gallery parameters of *Ips typographus* on the analysed trees.

Plot	Number of entrance holes per tree /per 1 dm^2 ± Sx (min.–max.)	Resin production 4th -5th day/7th day [level 0–4]	Number of galleries with nuptial chamber (min.–max.) [%]	Area of nuptial chamber ± Sx (min.–max.) [mm^2]
Irrigated	33.2 ± 13.6/0.21 ± 0.07 (18–55)/(0.14–0.32)	2.8/3.9	65.9 (0–100)	70.45 ± 21.38 (38.43–126.56)
Control	32.7 ± 17.5/0.22 ± 0.12 (17–65)/(0.10–0.43)	1.1/2.1	76.3 (44–100)	59.11 ± 19.11 (25.44–99.75)

Plot	Number of beetles in 1 gallery (min.–max.)	Number of maternal tunnels in 1 gallery (min.–max.)	Length of maternal tunnels ± Sx (min.–max.) [mm]	Number of eggs per 1 maternal tunnel (min.–max.)
Irrigated	0.7 (0–3)	0.9 (0–4)	12.33 ± 4.58 (5–18)	3.55 (0–13)
Control	1.92 (0–5)	1.5 (0–4)	17.76 ± 8.05 (7–43)	10.54 (0–35)

galleries was observed (Fig. 1). During the 4th and 5th days after the experiment establishment, the trees in the irrigated plot produced significantly more resin than the trees in the control plot (Pearson test, $\chi^2_{(4)} = 25.328$, $P < 0.01$). The average level of resin production on 4th and 5th days was 2.8 and 1.1 on the irrigated and control plot, respectively. A similar situation was observed on 7th day of the experiment, when the trees on the irrigated plot produced significantly more resin than the trees on the control plot (Pearson test, $\chi^2_{(4)} = 17.435$, $P < 0.01$). The average level of resin production on the 7th day was 3.9 and 2.1 on the irrigated and control plot, respectively. The assessment of trees on 12th day of the experiment revealed that the resin production in all galleries on both irrigated and control plots reached the level 4, which means that any further development of *Ips typographus* was stopped. In the galleries, parental adults were mostly absent or dead. The resistance of spruce stands to bark beetle infestation is strongly influenced by tree age, which was in our case 28 years. In our conditions, *Ips typographus* usually attacks spruce trees older than 60 years (Novotný, Zúbrik 2004), while trees older than 70 are optimal (Wermelinge 2004). The production of primary resin significantly varies between the trees on the plot as well as between the positions on the stem of every single tree (Christiansen & Horntvedt 1983). This may result from the creation of new resin ducts due to the influence of different factors, e.g. frost, drought, and probably also insect attack (Muloc & Christianse 1986). The production of primary resin greatly depends on the moderate stress of attacked trees in the near past, e.g. pruning or mechanical damage of stems, etc. Stressed trees produce more resin and are more resistant to the attack of bark beetles than trees that were not stressed in the past pers. observ.).

This theory is confirmed by the findings of Mrkva & Flora (1994) that indicate that tree resistance to bark beetle attack does not depend only on the actual condition of a tree, but also on the presence of stress in the past. This effect can also be seen on newly-created stand walls exposed to a single high dose of stress, which are significantly more attacked by bark beetle than trees growing in the forest interior (Zúbrik et al. 2008). Mechanical wounds of bark caused by uncovering of the galleries were sealed with resin in a short time, while the walls of galleries were sealed later and more slowly. This is probably linked with the ability of bark beetles to stop the production of primary resin, or to clog up resin ducts in galleries. In such cases, bark beetles overcome a so called primary resistance or the first level of tree defence based on the release of the primary resin when bark beetles attempt to bore the bark (Paine et al. 1997). We did not find a nuptial chamber in every gallery. On the irrigated plot, 65.9% of galleries had a nuptial chamber, while on the control plot a nuptial chamber was present in 76.3% of galleries. In many cases, adult bark beetles left the tree prior to the creation of a nuptial chamber, or a nuptial chamber was not created at a time of the gallery analysis.

The average area of the nuptial chamber was 70.45 ± 21.38 mm^2 and 59.11 ± 19.11 mm^2 on the irrigated and control plot, respectively. The difference in the area was not significant (ANOVA, $F(1;63) = 2.494$, $P = 0.121$).

The average number of adult beetles in one gallery on the irrigated plot was significantly lower than on the control plot (ANOVA, $F(1;106) = 24.711$, $P < 0.01$). The galleries on the irrigated plot contained 0.7 adult beetles on average, while the galleries on the control plot contained 1.92 adult beetles per gallery. At the time of gallery analysis (i.e. on 4th and 5th day after infestation), all adult beetles were alive. On the irrigated plot, no adult beetle was found in 21% of galleries with a nuptial chamber, while on the control plot at least one adult beetle was found in every gallery with a nuptial chamber. Although resin production was not visible in many galleries, beetles had left them.

The average number of maternal tunnels in one gallery system was not significantly lower on the irrigated plot than on the control plot (ANOVA, $F(1;62) = 3.097$, $P = 0.085$). One male beetle had on average 0.9 and 1.5 female beetles in the irrigated and control plot, respectively.

The average length of maternal tunnel on 4th and 5th day was significantly shorter on the irrigated plot than on the control plot (ANOVA, $F(1;82) = 6.906$, $P < 0.05$). The average length of the maternal tunnel was 12.33 ± 4.58 mm and 17.76 ± 8.05 mm on the irrigated and control plot, respectively (Fig. 3).

The average number of eggs per one maternal tunnel was significantly lower on the irrigated plot than on the control plot (ANOVA, $F(1;82) = 10.305$, $P < 0.01$). On the irrigated plot, 3.55 eggs occurred in one maternal tunnel on average, while on the control plot it was 10.54 eggs, i.e. almost three times more.

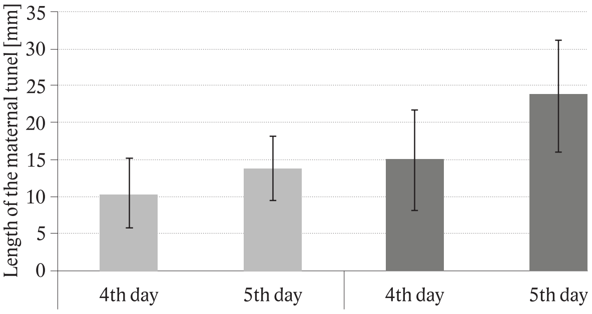

Fig. 3. Average length of the maternal tunnel on 4th and 5th day of experiment (mean ± Sx).

A complete gallery of *Ips typographus* is considered the gallery with minimum 20 eggs per one maternal tunnel (Mills 1986). Since in our case, the galleries were not complete, for the comparability of the data we calculated the average numbers of eggs per 1 mm of maternal tunnel. On the irrigated plot, 0.26 eggs occurred per 1 mm of maternal tunnel, while on the control plot, it was 0.56 eggs on average (median values were the same). This difference was confirmed significant (ANOVA, $F_{(1;82)} = 7.625$, $P < 0.01$). Matoušek et al. (2012) present that on trap trees situated in similar conditions (VLS Lipník, 500–660 m a.s.l.) the median number of eggs was 37 (average from I. and II. section), and the median length of the maternal tunnel was 65 mm (average from I. and II. section). From these values we calculated the value of 0.57 eggs per 1mm of maternal tunnel. This value corresponds with our average value on the control plot (0.56 eggs per 1 mm of maternal tunnel), which means that the resistance of drought-stressed trees on the control plot on 4th and 5th day of the experiment were similar to the resistance of trap trees.

The first hatched larvae were found in the galleries early, already on 6th day of the manipulated experiment. It means that the egg stage was extremely short; when extracting 2 days, which is the minimum time required for the excavation of a nuptial chamber, the egg stage lasted 4 days. Hennings (1908) presents 5.5 days as the shortest length of the egg stage at temperature of 24 °C and 55% humidity.

The results of the manipulated experiment, particularly the gallery parameters assessed after mating of parental adults indicate lower resistance of trees to bark beetle attack during rainless days with extremely high temperatures.

4. Conclusion

The experiment realised during summer swarming of *Ips typographus* showed significant differences between the irrigated and control plot in some gallery parameters of bark beetle. We found significant differences particularly in the gallery parameters that occur after the excavation of a nuptial chamber, or after mating of parental adults. This probably results from the delayed reaction of trees, which was caused by extreme temperatures and the overall slowdown of their defence reactions. The revealed differences prove that drought in combination with extreme temperatures significantly reduces defence reactions of spruce against bark beetle attack.

To conclude we can state that good timing of the experiment is difficult because the combination of the desired factors, such as swarming of bark beetles and suitable weather conditions (extreme drought and warmth) has to be ensured. This is one of the causes why only a few of such experiments have been performed so far.

Acknowledgements

This work was supported by the Slovak Research and Development Agency under the project no. APVV-0111-10 "Ecophysiological and spatial aspects of drought impact on forest stands under climate change" and APVV-0045-10 "Biological control methods of population dynamics of the insect pest proliferating on spruce and oak".

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