

# Effect of Selected Meteorological Factors on Forest Litter Moisture Content and Fire Danger Degree

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## Abstract

The aim of the study was to prove the effect of selected meteorological factors on the moisture content of forest litter and the degree of fire danger. The measurements were provided by the calibration of a measuring device for measuring the moisture content of Norway spruce litter. Field measurements were performed in surroundings of Zvolen, in the Scots pine (*Pinus sylvestris*), European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) stands, at the edge of the forest stand. In the period from April 1 to September 30, 2020, there were measured and analyzed the following meteorological factors: air temperature, total precipitations, and relative air humidity. The measured factor values were the subject of the analyses to determine the relation between the course of studied meteorological factors and the degree of fire danger. The historical fires, which occurred in the territory were studied and compared with the days of high and very high fire danger degree. The meteorological factors correlation coefficients significance evaluation results, in relation to the moisture content of forest litter at the stand edges and in the stand interior, showed that there is very important relationship between the air temperature, the relative air humidity, the fire danger index and the fire danger degree of the forest litter, especially at the edge of the stand. When comparing the interior of the stands of Scots pine, European beech, and Norway spruce, the most significantly are manifested the meteorological factors right in the spruce stand. The interior of the Scots pine and European beech stand is not so significant in relation to the moisture content of the litter, except for the index of fire danger, which appears to be an important characteristic for the degree of fire danger. The study also showed that different microclimate at the edge of the stand, as well as different microclimatic conditions inside the stands form conditions for different degrees of fire danger in those stands.

**Keywords:** European beech litter; Scots pine litter; Norway spruce litter; forest fire; litter moisture content.

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## 1 Introduction

The first preserved mentions of forest fires date back to the period around 1,200 A.C. A forest fire can be defined as a sudden partially or completely uncontrollable emergency, which is limited in space and time. Forest fire has a negative impact on all social functions of the forest. It is one of the most dangerous harmful factors which destroys forests in Slovakia every year. Except for the effects of atmospheric energy or persistent dry warm weather, fires are also caused by irresponsible human behaviour. The most common manifestations of irresponsible behaviour include handling open flames in places where it can spread uncontrollably, smoking, and burning shrubs and herbs in the spring. If forest fires are supported by wind and a suitable meteorological situation, they can affect a large area in a relatively short time. The fire weather conditions studies are known mainly from the region of southern

Europe (areas near the Mediterranean Sea) but also from Australia and North America, where it forms long-term fires. (Krakovský, 2004, Osvald, 2005, Stolina et al., 2000).

The aim of the study was realisation of an experiment focused on the effect of meteorological factors on the forest tree litter and the danger of forest fires in the surroundings of Zvolen town, especially in selected stands of Scots pine, Norway spruce and European beech. The experimental part also included measuring and analysis of the trend of air temperature, total precipitations, and relative air humidity during the fire season, i. e. in period April 1, 2020 - September 30, 2020.

## 2 Material and Methods

The experimental part was carried out in the summer of 2020 in the surroundings of the Zvolen town, in a special-purpose facility of the Technical University in Zvolen – Arboretum Borová Hora. Moisture content of fine fuel and forest litter was measured in three forest stands. These were forest stands of Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) located in the altitude range of 315 to 330 m above sea level.

The measurement of spruce litter was realised, first by the calibration of the measuring device (Fig. 1 - left) used for measuring the moisture content, i. e. Moisture Meter Wiltronics ME 2000, as the measuring device already contained calibrations of other mentioned forest litters.



**Fig. 1** Calibration process in the laboratory (left), field measurements of litter moisture content in the Arboretum Borova Hora (right)

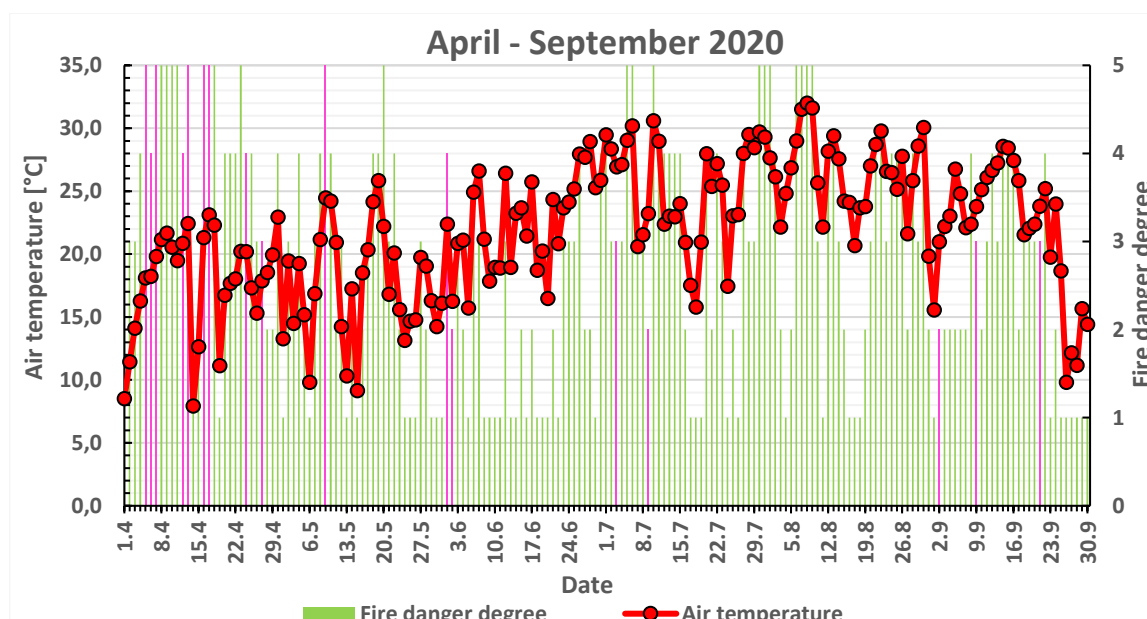
When calibrating the measuring device, there were followed the steps of the verified methodological procedure, which is introduced in the work of Korísteková, (2018). At the beginning of the calibration itself, it was necessary to obtain spruce litter, which was collected on the areas of the Arboretum Borova hora. From the obtained organic material (spruce litter) we prepared samples weighing 10 g, which we dried at constant temperature of 105 ° C for 24 hrs. to obtain an absolute dry material. After 24 hrs, the dried samples were placed in polyethylene film bags fitted with a sealing cap. A known volume of water was added to the samples in the bags, which represented the expected moisture content of the sample. The wetted samples in the bags were reinserted into other identical bags to minimize moisture content loss from the prepared samples. All samples prepared and moistened in this way were again placed in a hot-air oven and were dried at a temperature of 55 ° C for 24 hrs, to achieve stabilization of the moisture content in the prepared samples. After 24 hrs, the samples were repeatedly weighed to determine moisture content loss. Using a Moisture Meter Wiltronics ME 2000, the final moisture content value was determined and measured 3 times to achieve higher accuracy. The last step was to calculate the calibration curves.

After the calibration of the measuring device was completed, the moisture content measurements of the forest litter in the areas of the Arboretum Borova hora Arboretum were done (Fig. 1 - right). All field measurements were performed in already mentioned three forest stands (pine, spruce, and beech) in two parts for each stand, i. e. for the stand edge and for the stand interior. Measurements performed in selected days in the period from August 7, 2020, to September 4, 2020, were performed from c.a.

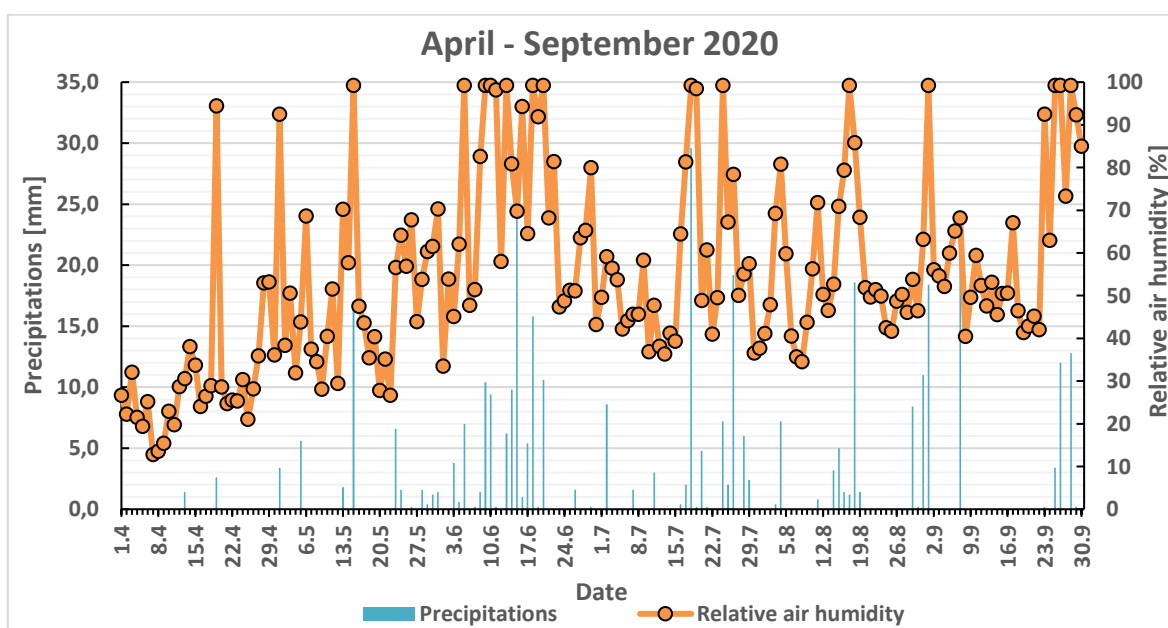
01.00 PM to 02.00 PM. As part of field measurements, air temperature, air flow rate, dew point and air humidity were also measured with a portable TestoTerm. At each of the 6 measuring stations, i. (stand interior and stand edge) a fixed measuring device Minikin i-line RTHi was also installed. Monitoring of other meteorological factors was provided by an automatic meteorological station EMS Brno, located at the station Arboretum Borova hora. The calculations of the fire danger index/ degree in accordance with the methodology of Škvarenina et al. (2004) were provided, using the EMS Brno software and the database of meteorological measurements of the Department of Natural Environment of the Technical University in Zvolen.

### 3 Results and Discussion

The course of the weather situation during the fire season, i. e. since April 1, 2020 to September 30, 2020, was expressed by the course of air temperature, precipitations, and relative air humidity. The graphical representation is introduced in Fig. 2 and 3.



**Fig. 2** Course of air temperature and fire danger degree in period April 2020 - September 2020 with indicating the days (pink colour) with wildfire occurrence.



**Fig. 3** Course of relative air humidity and precipitations in period April 2020 – September 2020

Analysis of weather course in the monitored period provides the following text. The meteorological parameters which were studied: air temperature, relative air humidity, total atmospheric precipitations and the fire danger which was set based on the fire danger index. Further, we comment in detail on the course of the weather for each month.

In April 2020, the monthly duration of sunshine was strongly above normal, April was extremely sunny. There were up to 29 sunny days in the Zvolen region with a daily duration of sunshine of more than 5 hours. According to the Arboretum Borova hora station data, it was a temperature-normal to slightly above-normal month (with a positive deviation of 0.3 °C for the Zvolen basin from the long-term average). There was recorded the maximum daily air temperatures on April 8 to 9 2020 and April 17, 2020, when the air temperature rose to 18.1 to 26.9 °C. April was extremely dry. Precipitation was extremely below normal in the Zvolen region (only 17% of the long-term average). The degree of fire danger was extremely high for the spring month, especially the first two decades of the month. The riskiest fire levels (4 and 5) accounted for 65%, which is the highest of all evaluated months. The high number of degrees 4 and 5 (high and very high fire danger) (Fig. 4), together with the course of the weather in April (Fig. 5), was also demonstrated by the number of fires in the wildland in the Zvolen region, see Tab 1.

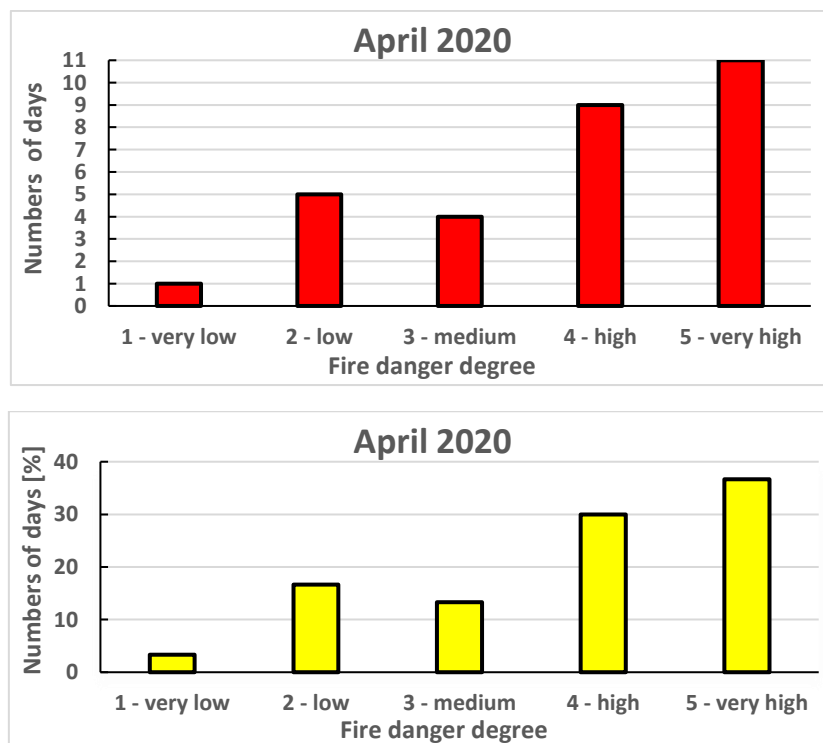
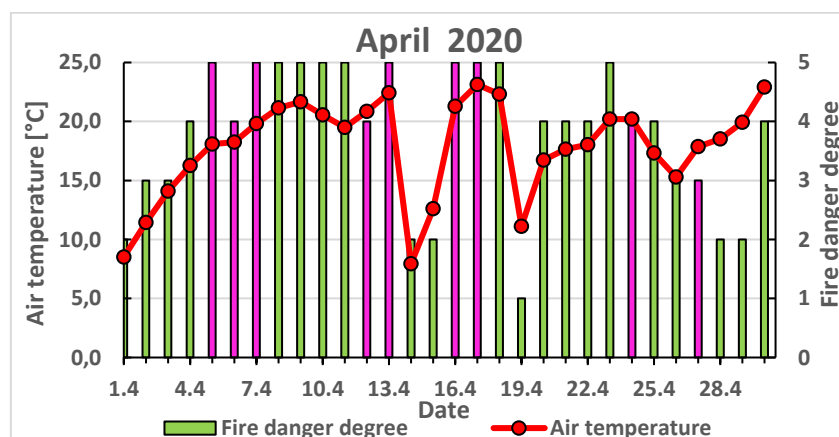
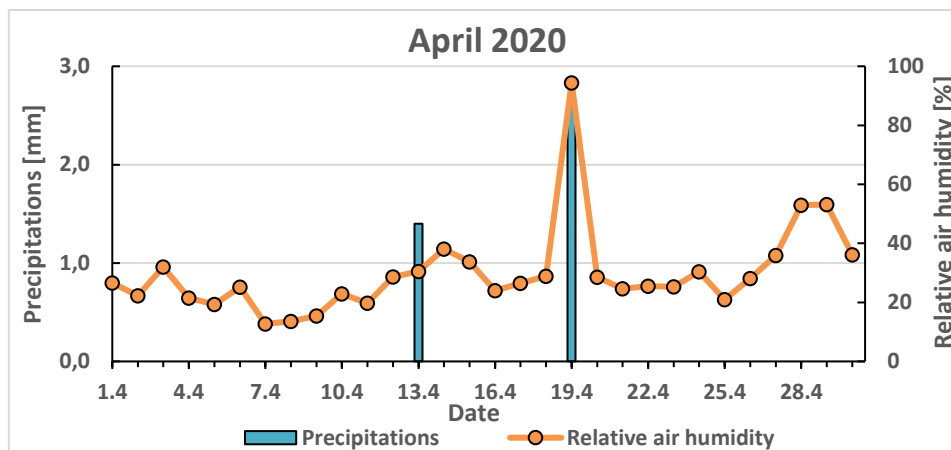


Fig. 4 Bar chart of absolute frequencies of the fire danger degree in April 2020 (top) and bar chart of relative frequencies of the fire danger degree in April 2020 (bottom)





**Fig. 5** Course of air temperature and fire danger degree in April 2020 (top) and course of relative air humidity and total precipitations in April 2020 (bottom)

May 2020, the monthly duration of sunshine in the Zvolen region was above normal (252 hours of sunshine). May was below normal in terms of temperature in the region. The average monthly air temperature was of 12.5 °C, with a negative deviation from the normal of 2.0 °C. Daily maximum air temperatures ranged from 20.7 to 28 °C and occurred on May 9 – 11 2020 and on May 19, 2020. During May 2020, there were recorded 5 summer days. Monthly precipitation totals were below normal. The monthly total precipitation was only 45 mm, which represents 58% of normal. There were recorded 3 storms. High values of cloudiness, lower temperatures and evenly distributed precipitation during the month conditioned a relatively favourable state of fire danger, where the low risk of forest fires dominated (first degree - 33%). Highest fire danger degree occurred only in two days in May (May 9, 2020, and May 20, 2020).

June 2020. The duration of sunshine in June was below normal (199 hours of sunshine). The month was slightly above normal in temperature. The average monthly air temperature was of 18.5 °C, with a positive deviation from the normal of 1.1 °C. The maximum daily air temperatures did not occur significantly until the end of the month, e. g. June 28, 2020, with air temperature above 30 °C. The first two decades of the month were significant, with precipitations. Precipitation in June was characterized by frequent local showers and storms. There were 18 precipitation days, 8 of them with a storm (e. g. on June 15, 2020). Overall, June was above normal in terms of precipitation (96 mm, which represents 123% of normal). The fire danger index was extremely favourable, with low levels of fire danger (very low to medium degree) dominating. High fire danger degree occurred only three times at the end of the month, the very high degree did not occur at all.

July 2020. The duration of sunshine was amounted to 281 h of sunlight. July was temperature normal. The average monthly air temperature was of 19.8 °C, with a deviation of 0.3 °C from normal. The maximum daily air temperatures ranged from 25.6 to 30.5 °C and occurred on July 6, July 10 to 11, and July 28, 2020. July rainfall was also relatively intense, with frequent storms. The precipitation total measured at the station was of 95 mm, which is 130 % of the long-term normal. On July 18, 2020, the daily precipitation total reached 30 mm. July 2020 was above normal in terms of precipitation. In terms of the fire danger index, the medium and high degree of fire danger prevailed.

August 2020. The monthly duration of sunshine was strongly above normal (265 h of sunlight, which represents 122 % of normal). In the region, whole August was above normal. The average daily air temperature was of 20.6 °C. The deviation from normal was positive and of 1.8 °C. The highest daily temperature occurred on August 8, 2020, when the maximum daily air temperature rose to 33.0 °C. August precipitation was very variable due to frequent local showers and storms. There was recorded a monthly total of 71 mm (111 % of normal), with the whole month being assessed as above normal in terms of precipitation. An interesting fact was observed that precipitations came to the region in three waves, from August 3 to August 4, 2020, then on August 11 to August 19, 2020, and finally on August 29 to August 31, 2020. In contrast, the periods between these waves were relatively dry (relative air humidity was of c.a. 40%), what caused a local increase in the fire danger index, e.g., on August 6 to

August 9, 2020, there were recorded a series of days with a very high fire danger degree. Overall, in August 2020, the high degree of fire danger dominated.

September 2020. The duration of sunshine in September was strongly above normal (195 h, which is 125 % of normal.) In the region, September should be characterized as an above-average month. The average monthly air temperature was of 15.5 ° C, with a positive deviation from the normal of 1.5 ° C. Daily maximum air temperatures rose to about 30 ° C and occurred on September 14 and September 15, 2020. September was also an above-average month due to precipitations. The monthly precipitation total was of 81 mm, that represents 137 % of normal total. The precipitation was not evenly distributed in September 2020, it fell only in the first and last decade of the month. The fire danger index was the highest in low fire danger degree. In the middle of the month, due to precipitation absence and relatively warm weather, a series of days with the high degree of fire danger occurred (September 8 to September 22, 2020).

The data from the Tab 1. points out present the fact that the occurrence of wildfires is related to the fire risky days determined according to the degree of fire danger. In the monitored period, totally 19 wildfires occurred in the surroundings of the Zvolen town. The majority (16 fires) occurred during fire risky days (days with a medium, high, and very high degree of fire danger). In comparison with the same period in 2018, analysed in the work of Ostrihoň (2019), where from the total of 27 wildfires, 18 fires occurred in fire risky days in terms of the degree of fire danger. From the comparison, we found that the number of wildfires decreased in the monitored period of 2020 to 2018, but nevertheless burned more in fire risky days. The distribution of forest fire risk in principle corresponded to the conditions published in the work of Vida et al. (2012). In percentage terms, wildfires in 2020 represent up to 84% of all wildfires in the region and 66% share of fires that occurred in the same period in 2018. In 2020, more than 58% of wildfires occurred in the most fire risky month, i. e. April.

**Tab. 1** Wildfires in the Zvolen region in the period April 1 to September 30, 2020

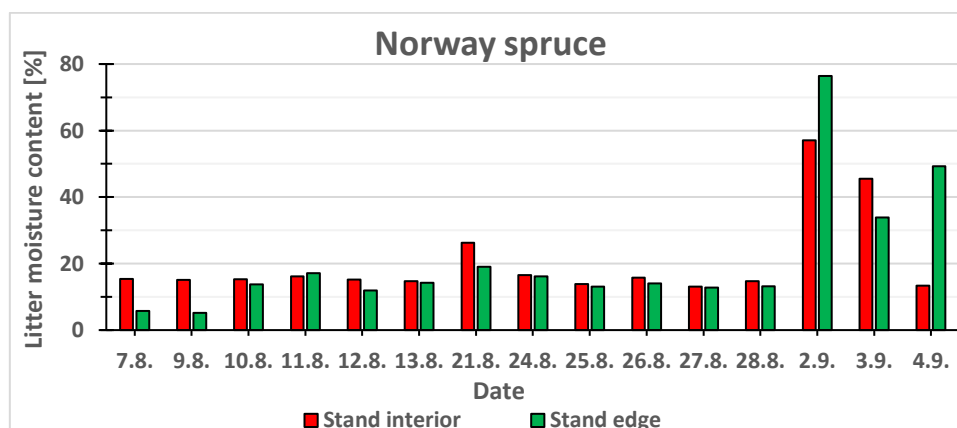
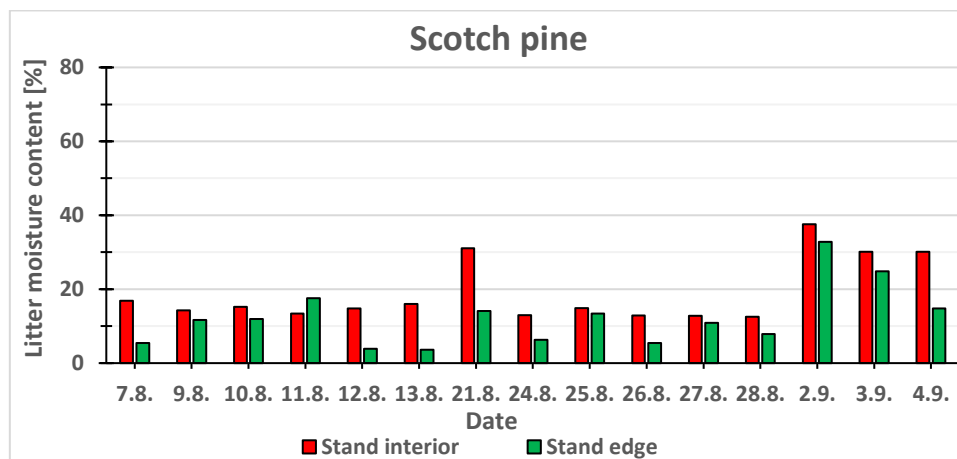
Emergency	Fire site	Fire initiation date	Fire initiation time	Direct damage (EUR)	Case of fire
Grassland fire *	Ostra Luka	05.04. 2020	06.45 PM	100	Smoking
Grassland fire *	Zvolen	06.04. 2020	01.40 PM	20	Smoking
Grassland fire *	Trnie	07.04. 2020	06.00 PM	0	Grass and shrubs burning
Grassland fire *	Ocova	07.04. 2020	11.40 PM	0	Grass and shrubs burning
Mixed-forest fire *	Lukavica	12.04. 2020	04.30 PM	0	Negligence of adults
Grassland fire *	Zvolen	13.04. 2020	11.10 AM	2,000	Electrical short
Grassland fire *	Zvolen	13.04. 2020	12.00 AM	0	Grass and shrubs burning
Grassland fire *	Zvolen	16.04. 2020	02.35 PM	0	Smoking
Wildfire *	Zvolen	17.04. 2020	06.40 AM	0	Setting fire in wildland
Grassland fire *	Sliac	24.04. 2020	05.50 PM	10	Smoking
Grassland fire *	Pliesovce	27.04. 2020	02.20 PM	50	Smoking
Grassland fire *	Zvolen	09.05. 2020	01.25 PM	10	Unknown
Parking area fire *	Zvolen	01.06. 2020	04.20 AM	1,000	Arson
Wildfire	Zvolen	02.06. 2020	02.12 AM	0	Smoking

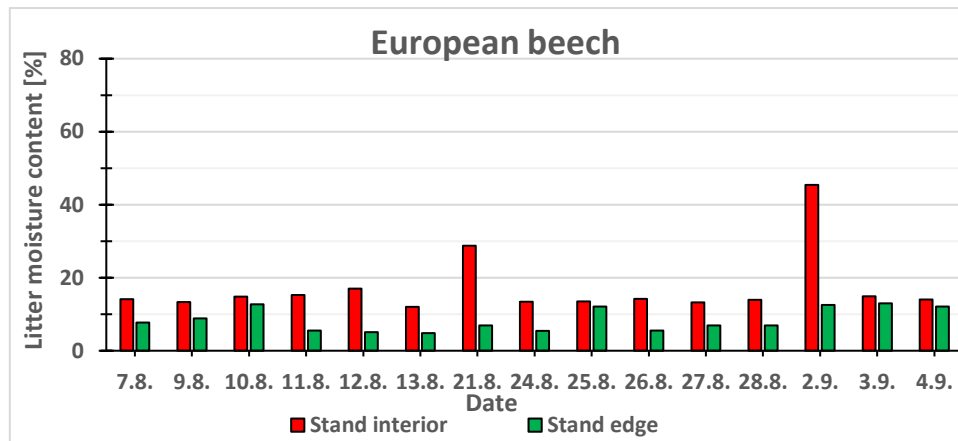
Emergency	Fire site	Fire initiation date	Fire initiation time	Direct damage (EUR)	Case of fire
Grassland fire *	Zvolen (near railway)	03.07. 2020	07.20 AM	10	Brake system failure
Parking area fire	Zvolen	09.07. 2020	10.15 PM	600	Unknown
Parking area fire	Zvolen	02.09. 2020	03.40 AM	5,000	Arson
Parking area fire *	Zvolen	09.09. 2020	11.18 AM	50	Electrical short
Wildfire *	Zvolen	21.09. 2020	11.35 AM	0	Waste incineration

\* Fires occurred in fire risky days (days with a medium, high and very high fire danger degree).  
Source: PTEÚ MV SR.

During field measurements performed in the Arboretum Borova hora, the course of litter moisture content was monitored. When monitoring the moisture content of the litter (Fig. 6), there was observed in European beech and Norway spruce stands higher moisture content of the litter inside the stand than at the edge of the stand. Exceptions were the measurement in spruce stands on September 2, 2020, and September 4, 2020. A smaller content of moisture in litter was caused by microclimatic conditions in the stand edge. Those allow the water to be evaporated from the litter.

The measurements confirmed the findings reported in some older works, such as Petrik et al. (1986). The warmest and driest microclimate showed the pine forest stand. Petrik et al. (1986) referred to this type of microclimate as the microclimate of sunny coniferous stands. Norway spruce stands were classified into the type of microclimate of shady coniferous stands. The beech stand, on the other hand, represented a type of microclimate of shady deciduous stands.





**Fig. 6** Comparison of litter moisture content course for pine, spruce and beech in the period August 7, 2020 – September 4, 2020, at the edge and inside the stand

Based on the analysis of the effect of selected meteorological factors on the moisture content of forest litter, we considered, according to Tab 2., the air temperature together with the relative air humidity to be very important meteorological factors in relation to the moisture content of the litter at all studied forest types at the edge of the stand.

**Tab. 2** Significance of correlation coefficients of air temperature, relative air humidity, fire danger index and fire danger degree with litter moisture inside and at the edge of the stand

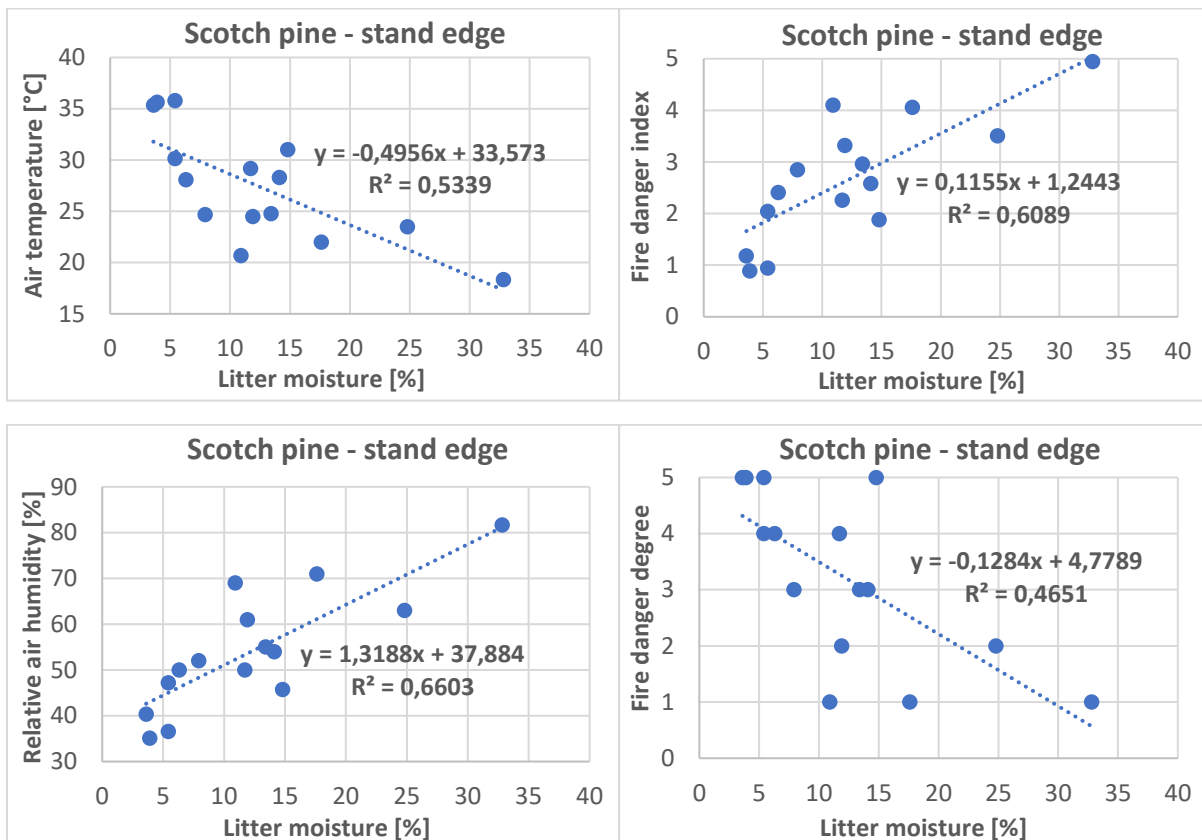
	Scotch pine ( <i>Pinus sylvestris</i> )		Norway spruce ( <i>Picea abies</i> )		European beech ( <i>Fagus sylvatica</i> )	
	Stand edge	Inside stand	Stand edge	Inside stand	Stand edge	Inside stand
AT	***	*	***	***	***	*
RAH	***	n.s.	***	***	***	n.s.
FDI	***	*	***	***	***	*
FDD	***	**	***	**	***	**

Verification of the significance of correlation coefficients between the parameters (AT - air temperature; RAH - relative air humidity; FDI - fire danger index; FDD - fire danger degree) and the moisture content of the studied litter types on the stand edge and inside the stand (significance level:  $\alpha < 0,1$  insignificant ns,  $0,1 < \alpha < 0,05$  \* not significant,  $0,05 < \alpha < 0,01$  \*\* significant,  $0,01 < \alpha < 0,001$  \*\*\* very significant, degree of freedom  $n = 15$  (according to Šmelko 1998).

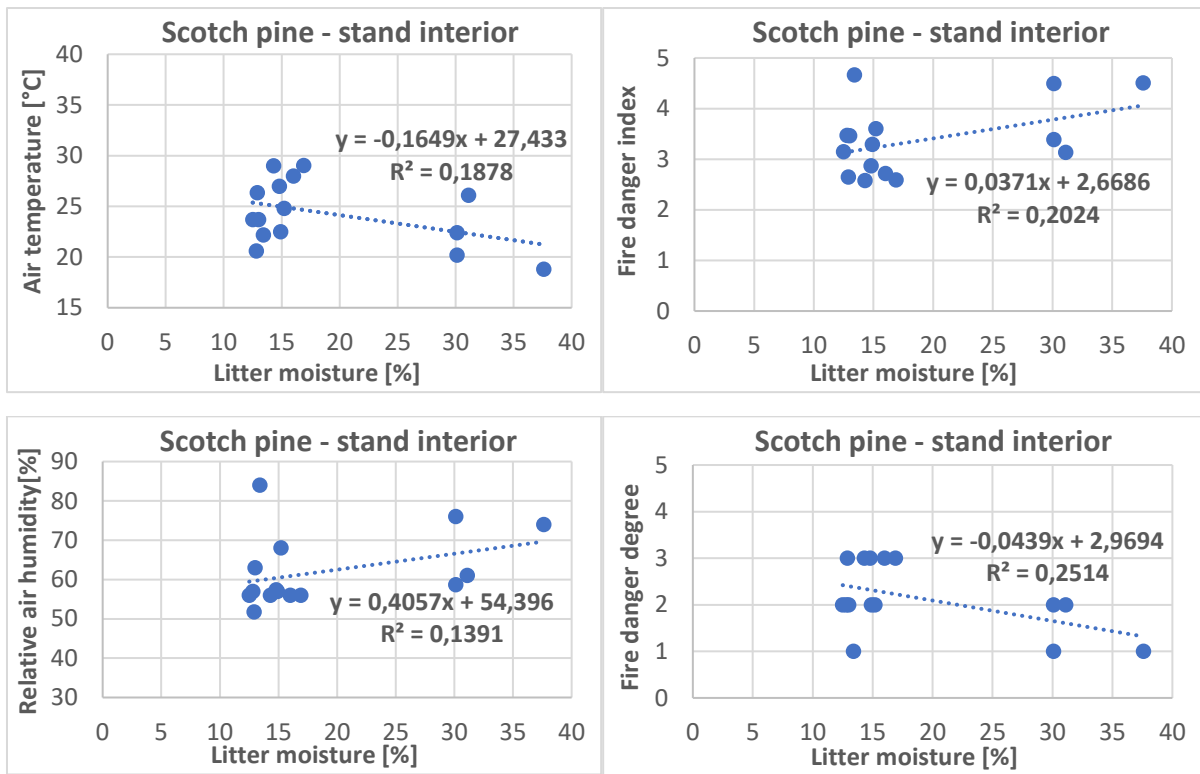
For testing, we used Student's paired test according to Šmelko (1998). The values of the index and the degree of fire danger also showed a very significant relation to the moisture content of the litter at the edge of the stand. Detailed graphical representations concerning the dependence of the monitored parameters on the moisture content of the litter are shown in figures 7 to 12. Correlation analysis of the dependence of the litter moisture content showed its statistically high significance to all monitored meteorological factors and subsequently also to the values of the fire danger degree and fire danger index. This dependence was most pronounced on the stand edges of all three monitored forest types. When monitoring this dependence inside the stands, a significant dependence of the moisture content of the litter on the monitored factors was found only in spruce stand. We assume that this is the result of a specific microclimate of the spruce stand. Spruce stand generally has a high retention (interception) for rainfall, while even during mild and medium rainfall the interior of spruce stands remains relatively dry,



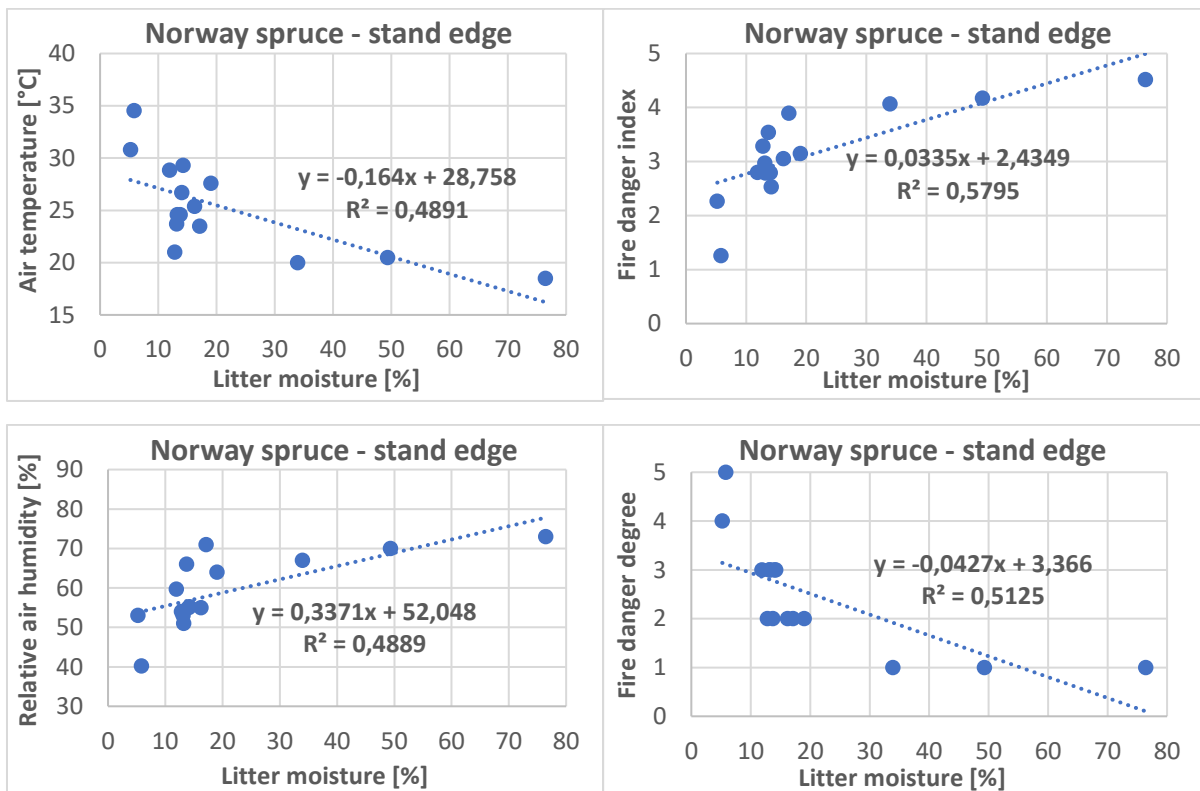
because through the dense and multi-layered crowns of spruce stands to the ground falls only a small volume of water from precipitation compared to land not covered with forest. Holko et al. (2009), Oreňák et al. (2010), for middle to lower-lying cultural spruce stands state that spruce crowns retain between 20 and 60 % of precipitation. This fact was also reflected in our results. In contrast, the pine stand, and partly also beech stand, retains significantly less rainwater in the crowns. According to Petrik et al., (1956), the interception of Scots pine is about 28 %, and according to Mind'áš et al. (2001), beech stand interception is about 19 – 20 % of the total precipitation in the open area. There is lighter in the pine and partly beech stands, and a more numerous undergrowth of herbs and grasses grows under their crowns, which causes a higher inhomogeneity of the litter moisture content, which is reflected in the higher variability of the results of our litter moisture content measurements.



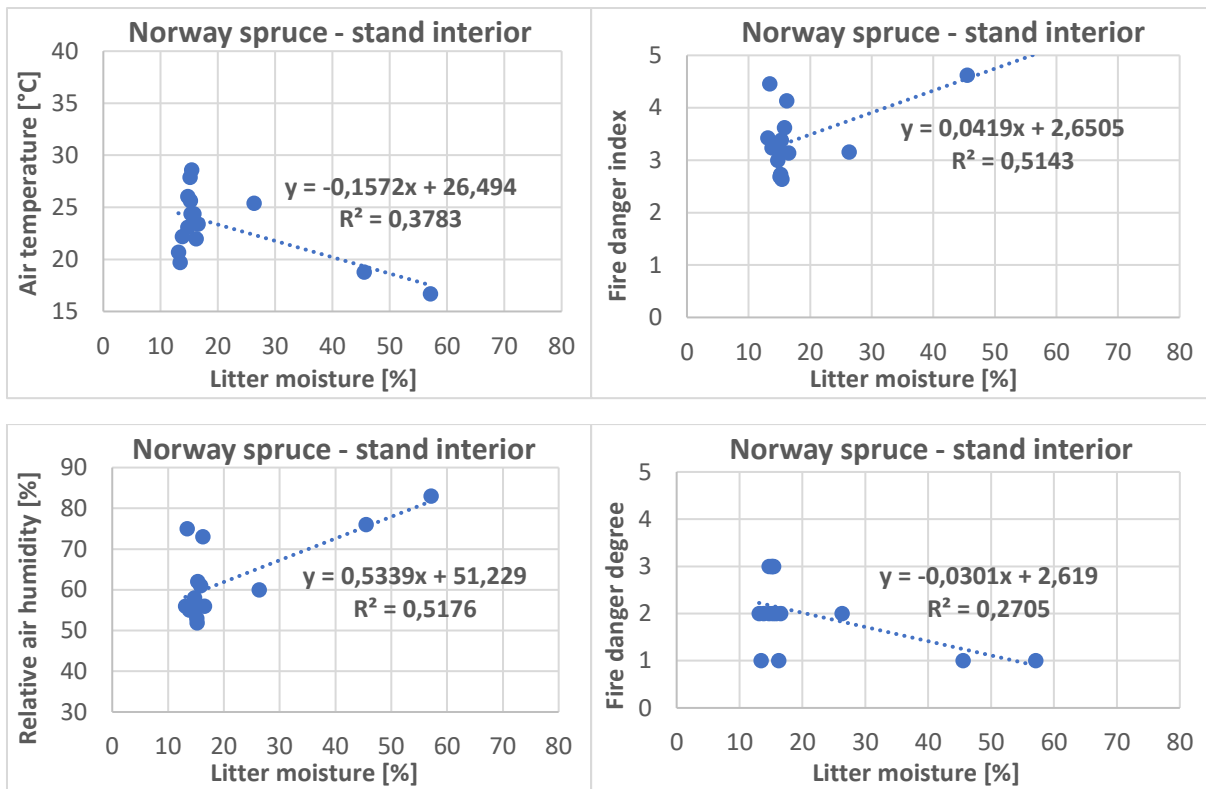
**Fig. 7** Dependence of forest pine litter moisture content at the edge of the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)



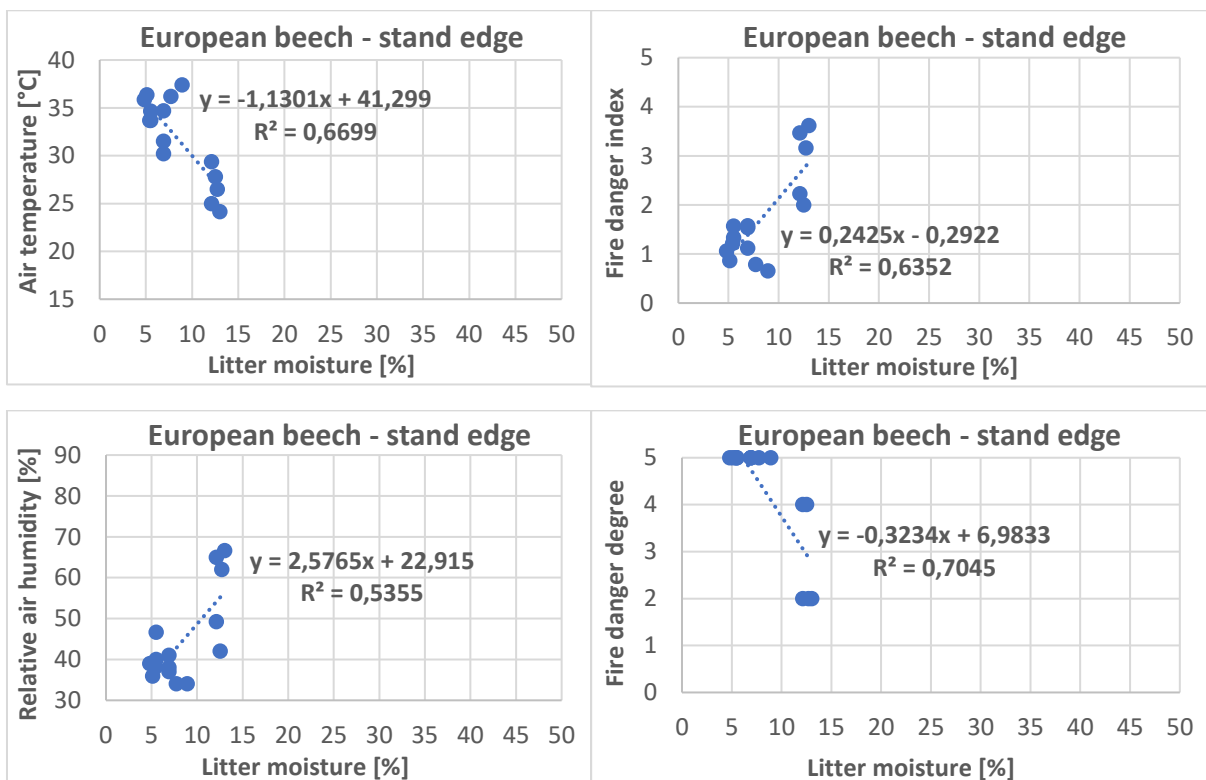
**Fig. 8** Dependence of forest pine litter moisture content inside the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)



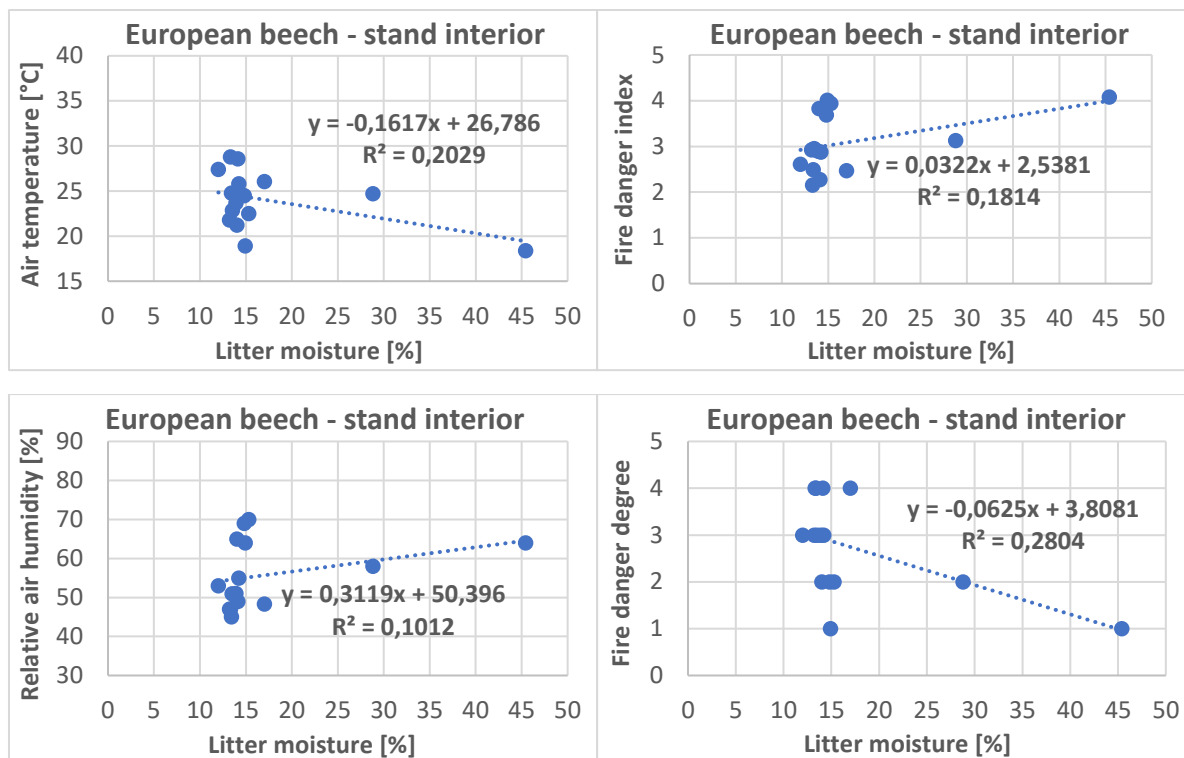
**Fig. 9** Dependence of forest spruce litter moisture content at the edge of the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)



**Fig. 10** Dependence of spruce litter moisture content inside the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)



**Fig. 11** Dependence of forest beech litter moisture content at the edge of the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)



**Fig. 12** Dependence of beech litter moisture content inside the stand on air temperature (top left), relative air humidity (bottom left), fire danger index (top right) and fire danger degree (bottom right)

#### 4 Conclusions

When analysing the influence of selected meteorological factors on the moisture content of forest litter (Norway spruce, Scotch pine, European beech) and forest fire danger, as well as during detailed study of weather course (especially air temperature, relative air humidity and total atmospheric precipitation) and fire danger in the fire season (April - September 2020), the following facts were found:

- In terms of air temperature, all months, except for May (slightly below normal), were above normal temperatures or at the normal level. In terms of total atmospheric precipitation, the first two months of the fire period (April and May 2020) were significantly below normal, especially April 2020, which was extremely dry. In the next months (June, July, August, and September 2020), the total precipitation ranged from 11 to 37 % above normal. The precipitation in that period was characterized mainly by local showers and summer storms.
- The studied fire season last 183 days, consisting of 43 days with high degree of fire danger (24 %), 42 days with very low degree of fire danger (23 %), 38 days with low degree of fire danger (21 %), 37 days with medium degree fire danger, and up to 23 days with very high degree of fire danger. While, for wildfires, the days with medium to very high fire danger are significant. Compared to the same season in 2018 (Ostrihoň, 2019), when c.a.77 % of fire risky days occurred in August, it was more than half of the days of the first decade with very high fire danger degree in August 2020, when the maximum daily temperature was in the range of 30 - 35 ° C. April 2020 was only slightly above average in temperature. However, it was extremely dry, which was reflected on number fire risky days.
- Field measurements of forest litter moisture content of Scots pine and European beech litter confirmed the fact published by Ostrihoň (2019), where the edge of the stand showed lower moisture content of the litter compared to the interior of the stand. This fact was also confirmed in spruce stand, which, except of two days, showed forest litter with higher moisture content at the edge of the stand than inside the stand.
- When evaluating the significance of the correlation coefficients of meteorological factors (air temperature, relative air humidity), fire danger index and the fire danger degree, in relation to the moisture content of forest litter at the stand edges and in the stand interior, we found that there is

very important relationship between the air temperature, the relative air humidity, the fire danger index and the fire danger degree of the forest litter, especially at the edge of the stand. When comparing the interior of the stands of Scots pine, European beech, and Norway spruce, the most significantly are the above-mentioned meteorological factors manifested right in the spruce stand. The interior of the Scots pine and European beech stand is not so significant in relation to the moisture content of the litter, except for the index of fire danger, which appears to be an important characteristic for the degree of fire danger. These differences are due to the type of forest stand and its ability to differently distribute precipitation, when passing the crowns.

- The study showed that different microclimate at the edge of the stand, as well as different microclimatic conditions inside the stands form conditions for different degrees of fire danger in those stands.

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