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Preliminary results of statistical analysis focused on the dependence between forest litter moisture and relative air humidity

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ABSTRACT: The results of the dependence of forest litter moisture on relative air humidity are presented in this paper. The dependence was studied applying the data obtained during a field survey in research plots situated in the Low Tatras Mountains territory. To process the statistical analysis the Statistica 8 software was applied. As a result of this analysis we expected to find the conversion index that can be used to calculate the fine fuel moisture based on the actual relative air humidity. The information on litter moisture (fine fuel component) is essential for the software for modelling fire behaviour. Results of analyses confirmed that the conversion coefficient between relative air humidity and forest litter moisture cannot be established, because the input data are highly variable. Therefore, the expected conversion factor confirming a significant dependence of litter moisture on air humidity was not obtained. On the contrary, the value of correlation coefficient was so low in all the measurements that it can be neglected.

Keywords: fine fuel moisture; Statistica 8; correlation coefficient; fire modelling

The issue of forest fires is tackled globally, and its importance has also increased in Slovakia, especially according to the impacts of ongoing climate change, which is manifested by extreme weather, which is closely linked with increased occurrence and severity of wildland fires and with the protection of natural environment, in particular the habitats of national or European importance, against its impacts (Monoši et al. 2015).

One of the issues of research on forest fires is the modelling of fire behaviour. For the modelling data serving as input data into the modelling are required. One of these inputs is also the moisture of fine fuel which, together with precise determination of the position of fire ignition place, is a key parameter to achieve the desired accuracy of modelling. In addition, the moisture of fine fuel is also one of the key parameters for determining the so-called fire weather index and determination of fire danger at all.

The paper presents the results of a statistical analysis of the relationship between relative air humidity and litter moisture, based on data obtained by a direct field survey at selected sites in the Low Tatras Mountains territory, in particular for the purpose of modelling and simulation of forest fires in the FARSITE environment.

In addressing the issue, a field survey was carried out at selected sites situated in the Low Tatras Mts. territory, followed by statistical evaluation of measured data and evaluation of possible application of those data to determine a conversion factor for determining the moisture content of the fuel, based on the altitude, slope and relative humidity, for the purpose of determining one of the input parameters in the fire behaviour modelling – the fine fuel moisture.

Forest fuel description. The fuel existing in the forest is organized in three superimposed layers: underground fuel, surface/ground fuel and crown fuel. Depending on which of the layers and/or of the forest components is burning in a fire, we can talk about the underground, surface and crown fire (Monoši et al. 2015).

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Underground fuel consists mainly of decaying vegetation – humus soil and underground wood that is composed of decaying dead roots and stumps. This combustible material is located between the litter and the mineral soil, which no longer contains a sufficient amount of organic material.

Surface fuel represents all living and dead vegetation over the rough humus soil layer, beginning with the litter and ending with the tops of small trees that do not interfere with the stand closure. Surface fuel is more diverse than underground and crown fuel. In this layer of fuel should be included: fallen leaves and pine needles, lichens and mosses, downed woody material such as fallen trunks, branches and twigs, live and dead herbaceous cover (herbs and grasses), shrubs and small trees.

The ground fire is primarily spread through the surface fine fuel (grass, pine needles and small wood material less than 2.5 cm in diameter). Major fuel particles contribute to a greater intensity of combustion and fire duration. The intensity of surface fire is the most important indicator of the likelihood of a crown fire occurrence (Monoši et al. 2015).

Crown fuel is made up of large trees and shrubs that reach the height of the treetops (Pyne et al. 1996). In crown fire, a major source of energy is represented by leaves, twigs and small branches. In a very intense crown fire, a major volume of woody biomass of large branches is also burned. For the propagation of a crown fire the above-mentioned intensity of surface fire, crown base height and moisture of leaves and twigs are crucial. For the spread of crown fires, the crown biomass density is important (Harrington 2005).

METHODS

Field survey. A field survey was aimed to measure the moisture of litter at selected sites situated in the Low Tatras Mts.

The Low Tatras Mts. are a massive mountain range in the Carpathian Mountains in Slovakia. It stretches from west to east and the length of the range is about 100 km. This geomorphological unit is divided into two parts, the Dumbier part, in which research sites are situated, and the Kralova Hola part. These two parts are divided by the Certovica saddle. This mountain range is among the most extensive protected areas here in Slovakia with an area of 205,085 ha. Our research sites are located in the southern part of the Low Tatras Mts. The surface of this area is mountainous and the research sites are situated at the altitude of ca. 470 m. The area is rich in tree species. The tree species composition of the stands in the surroundings of the research sites contains spruce, beech, larch and pine.

In general, the litter is a surface layer of organic material, which includes leaves, pine needles and broken twigs, still unaffected by humification process. The analysed litter was mostly made of pine needles.

The field survey was carried out in the period 4.10.–17.10.2013. The survey was carried out continuously over fourteen days, three times a day (at 7.00 AM, 3.00 PM and 7.00 PM), in three sites which were separated by a distance of approximately 10 m and determined in the top down direction. The first site was established at the uppermost point, where the highest terrain slope was 20°. The other two sites were located at positions with the terrain slope of 10° and 0°, i.e. on a flatland. First, the litter moisture was measured on the surface, then in the middle of the litter layer and finally the litter just above the soil. The sites were indicated in the field to provide the measurement at the same place.

For measuring the litter moisture we used an ME2000 Fine Fuel Moisture Meter (Wiltronics Research Pty. Ltd., Ballarat, Australia). The principle of operation of this device is based on electrical resistance.

Statistical analyses. For evaluating the measurements we used the tools of the Statistica 8 software. For processing the statistical analyses, calculation of dependences in the Statistica 8 environment, we also used information from the Slovak Hydrometeorological Institute, from the nearest weather stations.

The analysis was aimed to determine the correlation, i.e. the relationship between two characteristics in a statistical file. In this case, we investigated the relationship between relative air humidity and litter moisture content. Overall, we investigated the following statistical indicators: arithmetic mean, minimum, maximum, variance, standard deviation, correlation coefficient, regression coefficient.

RESULTS

Here we present the overall results of statistical data processing in graphical and text form only for the slope positions of 0° and 20°.

In the analyses the pre-calculated values of correlation coefficients were applied (Table 1), defining the dependence of litter moisture on relative air humidity. The aim of this analysis was to calculate a conversion index to determine the moisture of fine fuel without the need to perform field measurements. Further we present the overall results for the selected positions.

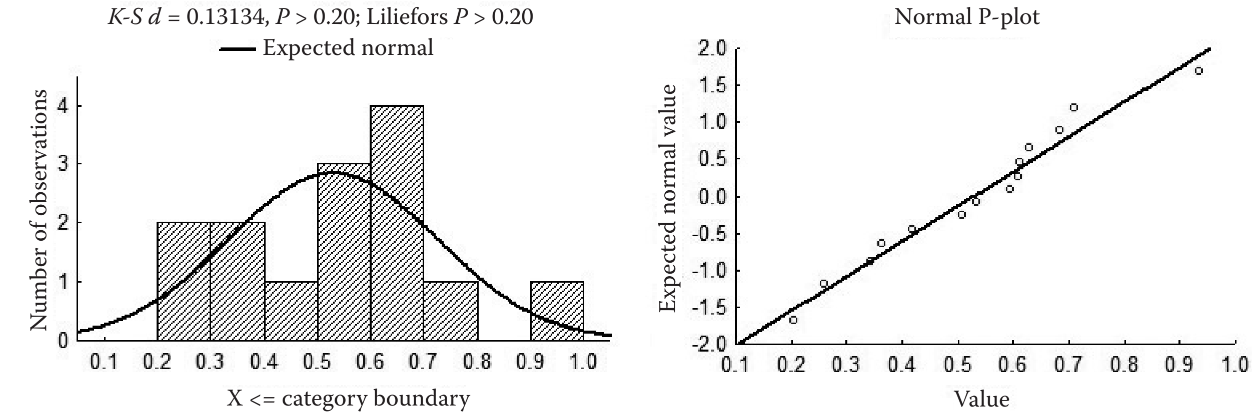
Table 1. Correlation coefficients calculated for each site, time and day

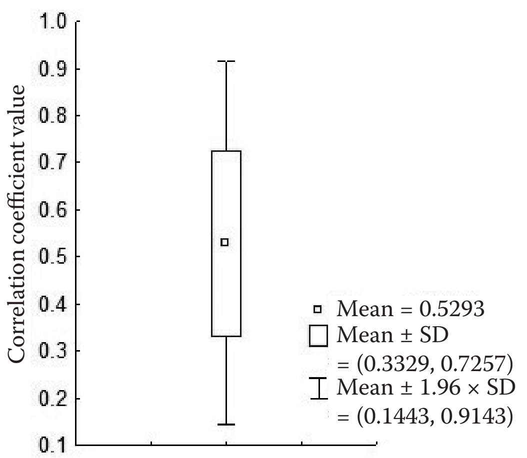
Date	Time								
	7.00 AM			3.00 PM			7.00 PM		
	slope (°)								
	20	10	0	20	10	0	20	10	0
4.10.2013	0.34253	0.40632	0.50805	0.51720	0.75914	1.00000	0.40000	0.43651	0.59127
5.10.2013	0.64130	1.09928	0.68406	1.03030	1.47879	1.81515	0.62843	0.83922	0.64608
6.10.2013	0.65833	0.72870	0.93611	1.30556	0.88889	1.56556	0.60721	1.09640	1.15225
7.10.2013	0.79593	0.49756	0.41870	0.62576	0.66136	0.38030	0.54722	0.34653	0.64236
8.10.2013	0.34848	0.33182	0.26061	0.56389	0.41528	0.30208	0.61600	0.47400	0.27800
9.10.2013	0.58497	0.48431	0.61176	0.50741	0.69037	0.88815	0.34464	0.44702	0.66667
10.10.2013	0.24708	0.25292	0.36357	0.28803	0.58419	0.44872	0.19000	0.33259	0.34222
11.10.2013	0.33011	0.29319	0.20466	0.36131	0.36071	0.36071	0.28756	0.32089	0.27022
12.10.2013	0.33875	0.30750	0.34375	0.33216	0.61462	0.37018	0.27195	0.30610	0.32764
13.10.2013	0.62946	0.43760	0.70891	0.92678	0.74372	0.83115	0.61963	0.28904	0.76027
14.10.2013	0.51891	0.58458	0.60995	0.73333	0.57333	1.00167	0.47067	0.59400	0.66933
15.10.2013	0.53296	0.51444	0.53556	1.32587	0.96020	1.04478	1.05000	0.49706	1.17500
16.10.2013	0.84235	0.46745	0.62941	0.84908	0.58681	0.71905	0.71134	0.45086	0.62715
17.10.2013	0.68488	0.70584	0.59519	1.20000	1.05430	1.24731	0.79759	0.50562	1.01325

From Fig. 1 the minimum value of correlation coefficient 0.204660 is evident while the maximum value is 0.936110. Standard deviation is 0.196425 and the arithmetic mean is 0.529306. This graph was developed for the slope of 0° (flatland) and the time 7.00 AM.

Fig. 2 shows the minimum value of correlation coefficient 0.302080 and the maximum value 1.815150. Standard deviation was calculated to be 0.468622 and the arithmetic mean was 0.855344. This was developed for the slope of 0° (flatland) and the time 3.00 PM.

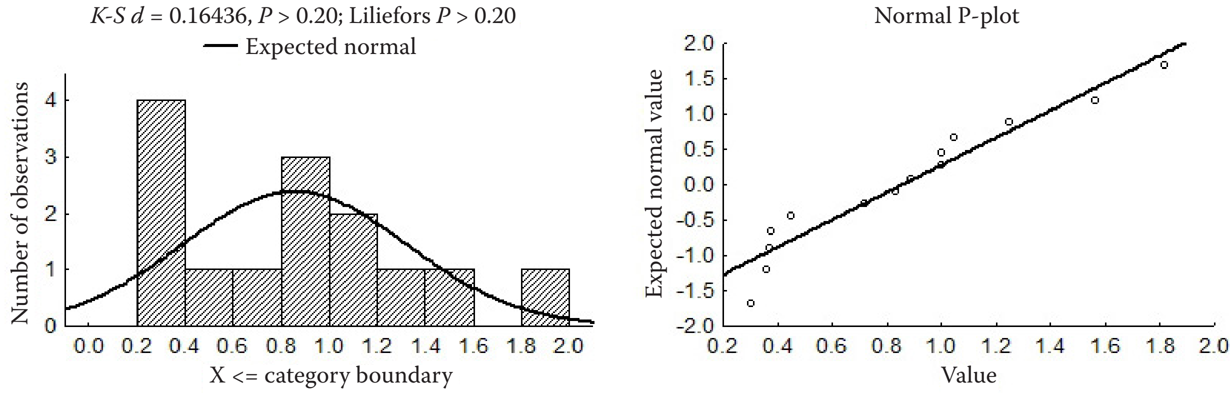
In Fig. 3, the minimum value of correlation coefficient was set to 0.2720220 and the maximum value to 1.175000. Standard deviation was set to

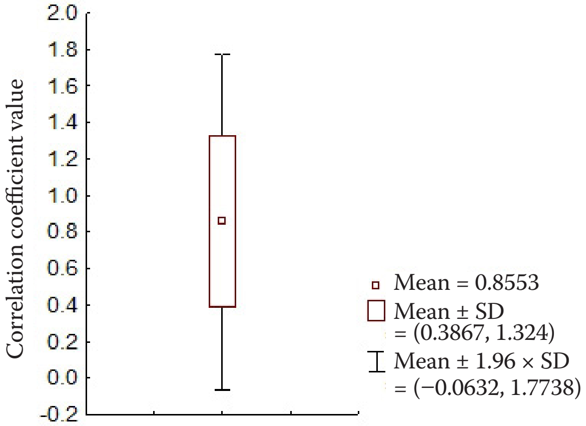




summary statistics:
valid N = 14, mean = 0.529306,
minimum = 0.204660,
maximum = 0.936110,
standard deviation = 0.196425

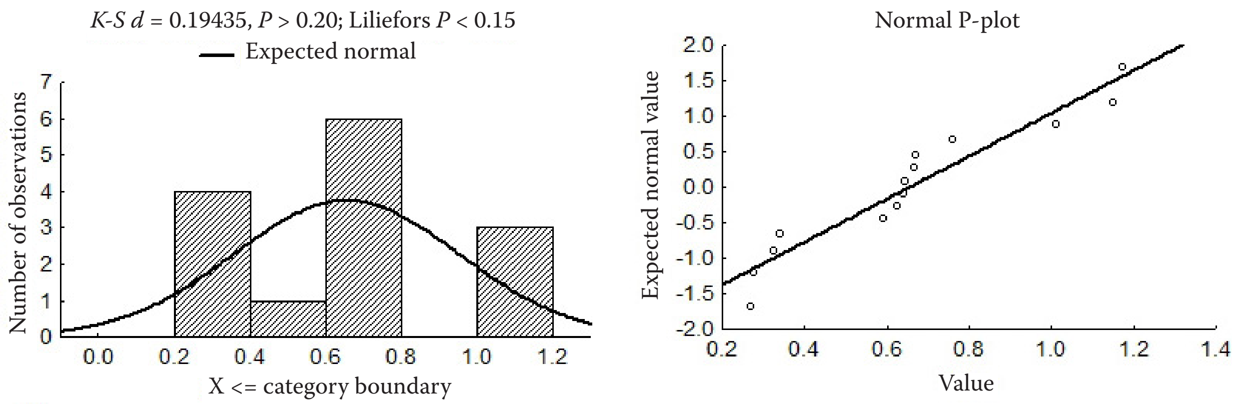
Fig. 1. Dependence of litter moisture on air humidity – slope 0°, 7.00 AM

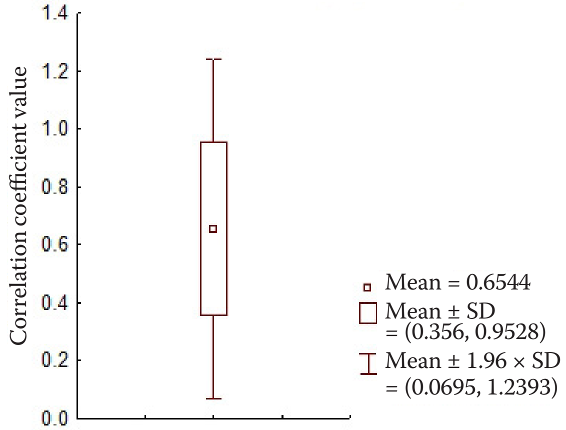




summary statistics:
valid N = 14,
mean = 0.855344,
minimum = 0.302080,
maximum = 1.815150,
standard deviation = 0.468622

Fig. 2. Dependence of litter moisture on air humidity – slope 0°, 3.00 PM





summary statistics:
valid N = 14,
mean = 0.654408,
minimum = 0.270220,
maximum = 1.175000,
standard deviation = 0.298416

Fig. 3. Dependence of litter moisture on air humidity – slope 0°, 7.00 PM

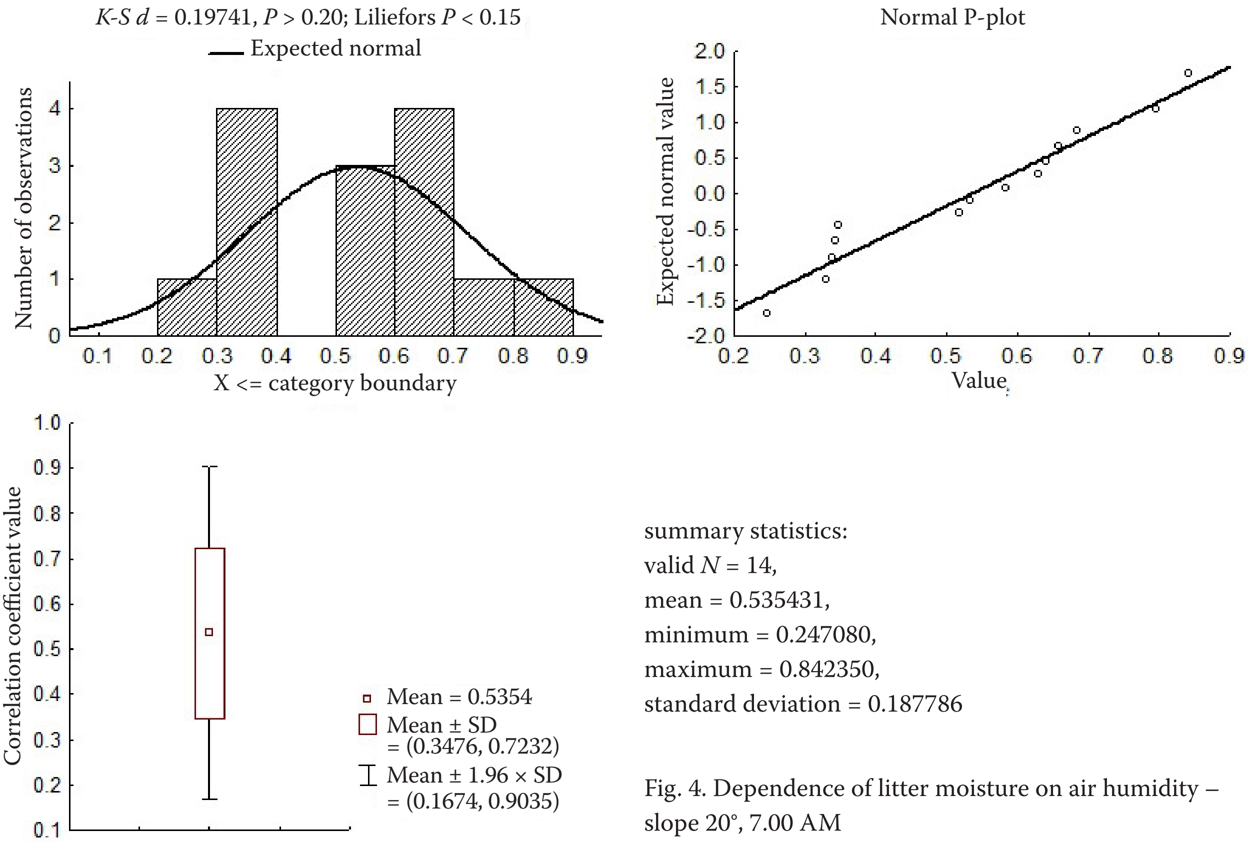


Fig. 4. Dependence of litter moisture on air humidity – slope 20°, 7.00 AM

0.298416 and the arithmetic mean to 0.654408. This was developed for the slope of 0° (flatland) and the time 7.00 PM.

From Fig. 4 it is evident that the minimum value of correlation coefficient is 0.247080 and the maximum value is 0.842350. Standard deviation is 0.187786 and the arithmetic mean is 0.535431. This graph was developed for the slope of 20° and the time 7.00 AM.

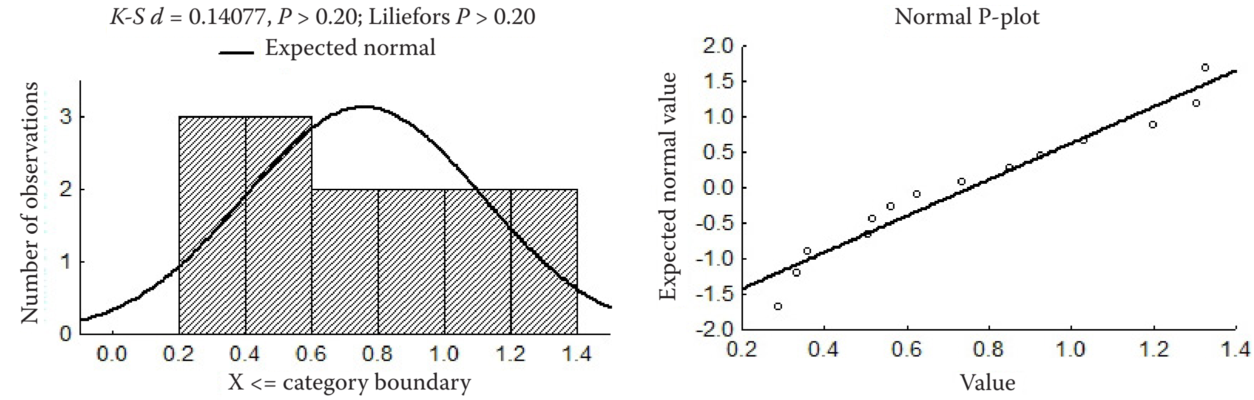
In Fig. 5 we can see the minimum value of correlation coefficient to be 0.288030 and the maximum value to amount to 1.325870. This was developed for the slope of 20° and the time 3.00 PM.

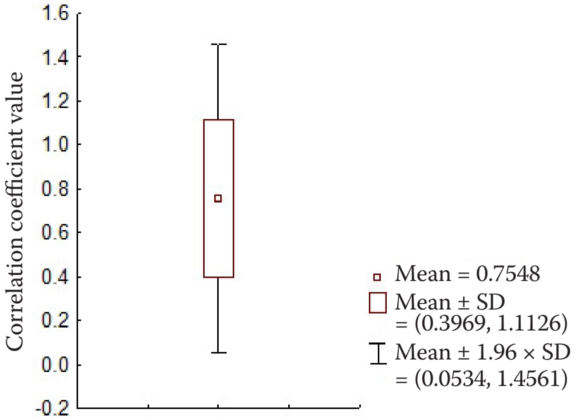
Standard deviation has the value 0.357833 and the arithmetic mean is 0.754763.

Fig. 6 shows the minimum value of correlation coefficient 0.190000 and the maximum value 1.050000. In this case, standard deviation is 0.232204 and the arithmetic mean is 0.538731. This graph was developed for the slope of 20° and the time 7.00 PM.

In these box graphs (Fig. 7) we have used the measured values of litter moisture content in sites with slope of 0° (Fig. 7a), 10° (Fig. 7b) and 20° (Fig. 7c). Each box graph contains the visualisation of the correlation coefficient range for three times: 7.00 AM, 3.00 PM, and 7.00 PM.

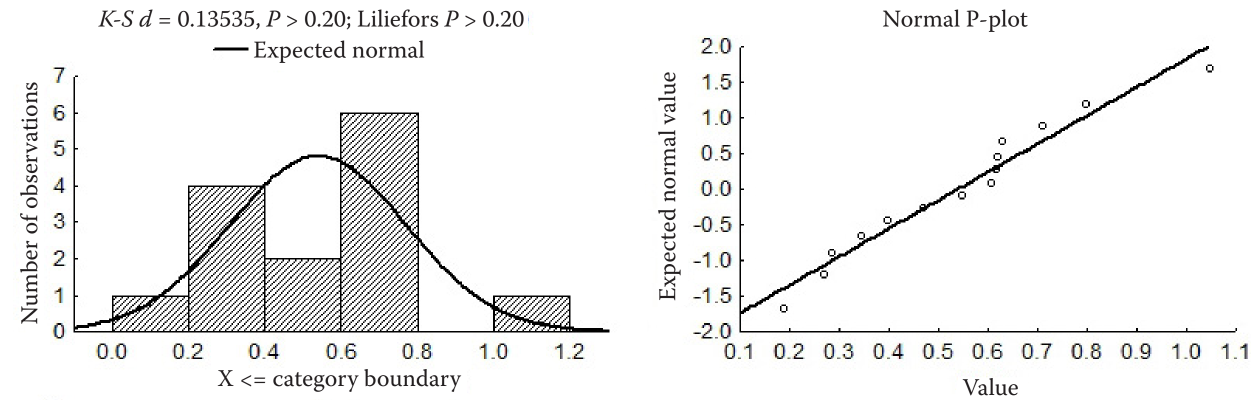
In the first case (Fig. 7a), the measurements were done on the flatland. In this case the largest range of litter moisture values was at 3.00 PM. In case of morning measurements we can see that the values did not vary to such an extent. Their variability was even smaller than that of litter moisture measurements in the evening. It is so because that during the day when it was warmer, the moisture content decreased in the upper layer of the litter, which made this moisture move towards the lower layers. And that is the reason, why there is a large range of values. In the second case (Fig. 7b), we used the correlation coefficient values for the site with the slope of 10°. There is a small difference in measurements during the day. This can be caused by the fact that in the sites with steeper terrain slope the change in the moisture content is more proportional than on the flatland. This is a logical result that can be explained by higher runoff caused by a rain event downward the slope and not towards the next layer like on the flatland. The box graph in Fig. 7c shows the values measured at the steepest site, where the terrain slope was 20°. Here the situation is similar to that documented in the previous graph. Similarly, the range of correlation coefficient values is narrower than in the case of the flatland.

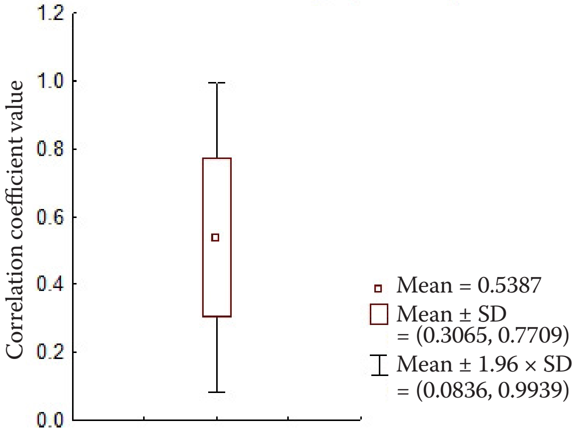




summary statistics:
valid N = 14,
mean = 0.754763,
minimum = 0.288030,
maximum = 1.325870,
standard deviation = 0.357833

Fig. 5. Dependence of litter moisture on air humidity – slope 20°, 3.00 PM





summary statistics:
valid N = 14,
mean = 0.538731,
minimum = 0.190000,
maximum = 1.050000,
standard deviation = 0.232204

Fig. 6. Dependence of litter moisture on air humidity – slope 20°, 7.00 PM

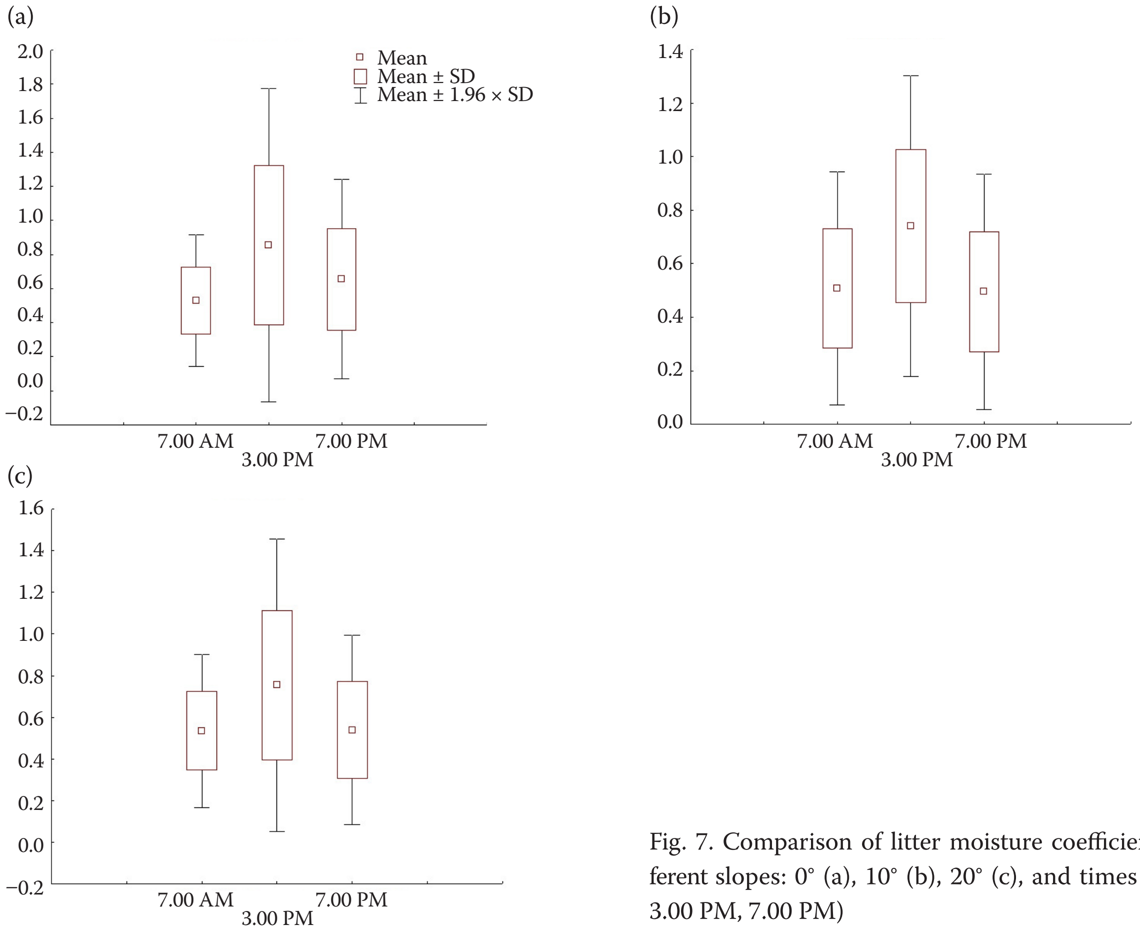


Fig. 7. Comparison of litter moisture coefficients for different slopes: 0° (a), 10° (b), 20° (c), and times (7.00 AM, 3.00 PM, 7.00 PM)

DISCUSSION

The determination of the relationship between forest litter moisture content and relative air humidity is not a well-known issue either in the world or in conditions of Central Europe. The research in this field is more oriented to finding the methods to automate the process of its measurement (Schunk et al. 2016), or to model the fine fuel (also forest litter) moisture (Viney 1991; Schaap et al. 1997; Ogee, Brunet 2002).

For the measurement of the moisture content of forest litter, it is generally known that there is not available any easy-to-use method for automated measurements. Therefore, a field survey is used for this purpose in particular.

Existing research focused on the relationship between atmospheric conditions and forest fuel parameters is more oriented to soil parameters than to the litter ones (Horton, Wierenga 1983; Costello, Braud 1989).

According to the particularity of the problem solved in this paper, it could be stated that it belongs among the first works dealing with this issue, focusing in particular on research on the dependence between relative air humidity and forest litter moisture (and/or water content) in our conditions. The obtained results showed the necessity to continue the measurements to find a relationship between both parameters observed, to automate the process of forest litter moisture content assessment and also to further use the values of this parameter in modelling the forest fire behaviour and also for the purposes of assessment of the forest or wildland fire danger.

CONCLUSIONS

The paper deals with an analysis of the dependence between forest litter moisture and relative air humidity to calculate the conversion index which could be used to determine the moisture content of fine fuels in real time without the need for implementation of field measurements. This information belongs to key inputs for the modelling of fire behaviour. The possibility of its deduction from the actual meteorological parameters would greatly facilitate the deployment of software for modelling fire behaviour in the operational practice of rescue services.

Data measured in the field were used to determine the correlation coefficient defining the dependence of litter moisture on relative air humidity. These factors were further used to determine the conversion index, whereby it would be possible to determine the moisture content of fine fuels without a field survey, only from the data provided by the Slovak Hydrometeorological Institute.

We can state according to results of the analyses that it is not possible to establish clearly the conversion index for the calculation of the fuel moisture content, based on the data on air humidity, because the input data are highly variable. At the research sites, the sufficiently significant dependence between the litter moisture and relative air humidity has not been reflected.

References

Costello T.A., Braud H.J. (1989): Thermal diffusivity of soil by nonlinear regression analysis of soil temperature data. Transactions of the ASAE, 32: 1281–1286.

Harrington S. (2005): Measuring Forest Fuels: An Overview of Methodologies, Implications for Fuels Management. Working Paper No. 19. Madison, Forest Guild Research Center: 22.

Horton R., Wierenga P.J. (1983): Estimating the soil heat flux from observations of soil temperature near the surface. Soil Science Society of America Journal, 47: 14–22.

Monoši M., Majlingová A., Kapusniak J. (2015): Lesné požiare. Žilina, EDIS: 200.

Ogee J., Brunet Y. (2002): A forest floor model for heat and moisture including a litter layer. Journal of Hydrology, 255: 212–233.

Pyne S.J., Andrews P.L., Laven R.D. (1996): Introduction to Wildland Fire. New York, John Wiley & Sons: 773.

Schaap M.G., Bouten W., Verstraten J.M. (1997): Forest floor water content dynamics in a Douglas fir stand. Journal of Hydrology, 201: 367–383.

Schunk C., Ruth B., Leuchner M., Wastl C., Menzel A. (2016): Comparison of different methods for the *in situ* measurement of forest litter moisture content. Natural Hazards and Earth System Sciences, 16: 403–415.

Viney N.R. (1991): A review of fine fuel modelling. International Journal of Wildland Fire, 1: 215–234.

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