JOURNAL OF FOREST SCIENCE, *64*, 2018 (8): 331–339

https://doi.org/10.17221/46/2018-JFS

Functional effects of forest ecosystems on water cycle – Slovakia case study

Jozef MINĎAŠ [1], Martin BARTÍK [2], Jana ŠKVARENINOVÁ [3], Richard REPISKÝ [1]

[1]*Institute of Ecology and Environmental Sciences, University of Central Europe, Skalica, Slovak Republic*

[2]*Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovak Republic*

[3]*Department of Applied Ecology, Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, Zvolen, Slovak Republic*

**Corresponding author: j.mindas@sevs.sk*

Abstract

Minďaš J., Bartík M., Škvareninová J., Repiský R. (2018): Functional effects of forest ecosystems on water cycle – Slovakia case study. J. For. Sci., 64: 331–339.

The paper presents the results from three different experimental plots in mountain areas in Slovakia. Annual interception losses varied in mature forest stand in Poľana Mts. (850 m a.s.l.) in mixtured (spruce, fir, beech) from 10.6 to 23.5%, in spruce from 20.5 to 35.5% and in beech forest from 8.8 to 26.9%. Horizontal precipitation reduces long-term average of interception loss by 3.2% (mixtured and spruce) and 2.9% for beech forest. Decline process in supramontane spruce forest has significant influence on interception process in climax spruce stand in Červenec. Mean biweekly interception loss in the central crown zone near the stem during growing seasons was 76.9% in living and 69.2% in dead forest. In the gap canopy interception loss was observed 11.7% in living and 17.9% in dead forest, in the dripping zone under the crown periphery 11.1% in living and 25.7% in dead forest. Results from the experimental catchment Lomnistá dolina showed that forest ecosystems increase the variability of rainfall amounts infiltrated to the soil environment in mountain watersheds, interception loss varied in a wide range: from 42 up to –10% due to altitudinal influence, tree species composition, stand age, and horizontal precipitation occurence.

Keywords: precipitation; throughfall; stemflow; interception; mountain watersheds

Forest ecosytems as an integrated part of catchments "manage" a high proportion of the water for domestic, agricultural, industrial and ecological needs in both upstream and downstream areas. A key challenge faced by landscape, forest and water managers is to maximize the wide range of multisectoral forest benefits without detriment to water resources and ecosystem functions (Chang 2013). To address this challenge, there is an urgent need for a better understanding of the interactions between forests/trees and water, for awareness raising and capacity building in forest hydrology, and for embedding this knowledge and the research findings in policies (Vyskot et al. 2003; Calder et al. 2007).

Interception is the part of the rainfall that is intercepted by the earth's surface and which subsequently evaporates. In this definition the earth's

Supported by the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic and Slovak Academy of Sciences – VEGA, Grants No. 1/0367/16, No. 1/0589/15, No. 2/0101/14, and No. 1/0463/14, and by the Slovak Research and Development Agency, Projects No. APVV-0423-10 and No. APVV-0303-11.

surface includes everything that becomes wet after a rainfall event and that dries out soon after. It includes: vegetation, soil surface, litter, build-up surface, etc. How much of the precipitation evaporates depends on land cover characteristics, rainfall characteristics, and on the evaporative demand (Chang 2013). Interception in temperate mountain European forests, in the most cases, can amount up to 7–52% of precipitation, which is a significant part of the water balance (Minďáš, Škvarenina 2010). One can distinguish many types of interception, which can also interplay with each other. For example canopy, forest floor, fog, snow, and urban interception (Levia et al. 2011).

The conversion of precipitation to groundwater and streamflow is reduced mainly by the interception of forests, the ground cover (herbs and shrubs) and by evaporation from the tree canopy. Further reduction is through transpiration of soil moisture from foliage.

Interception is a unique key process of precipitation transformation in forest ecosystems and has several different roles in the hydrological cycle. Rainfall interception loss of forest is an important component of water balance in a forested ecosystem. Canopy interception is determined by the difference between gross precipitation and the sum of throughfall and stemflow precipitation (Chang 2013).

The most important role of forest ecosystems is as a rainfall reducer (amount of water as well as a cinetic energy of rain drops), causing a significant amount of rainfall to be directly fed back to the atmosphere which is not available for infiltration. Second, interception influences the spatial distribution of infiltration (Gömöryová et al. 2013). This has large influences on the soil moisture pattern and on subsurface flow paths. Finally, interception redistributes the water flows in time. Due to the filling of the spatial variable storage capacity and rainfall, the delay time is not homogeneous in space. This paper shows that interception is a key process in the hydrological cycle. It involves significant fluxes in the water balance and influences the subsequent processes both in quantity and timing. It is an important cause for non-linear behaviour of catchments. The role of interception in the hydrological cycle is crucial (Levia et al. 2011).

Since the beginning of the 90s (20th century) took place in Slovakia systematic study of the water balance of forest ecosystems in terms of quantitative and qualitative parameters (Minďáš, Škvarenina 1995; Střelcová et al. 2006; Hríbik et al. 2012). Experimental measurements have been concentrated in mountain regions due to their importance in hydrological regime of landscape.

MATERIAL AND METHODS

In this paper we present the results of precipitation measurements in forest ecosystems in Poľana and Western Tatras. Basic characteristics of the experimental plots (Hukavský grúň and Červenec) is presented in Table 1.

Detailed description of the experimental plots and methodology can be found in Minďáš (2003) and Oreňák et al. (2013). At the experimental plot Červenec also automatic rainfall gauges were used (Met One 370; Met One Instruments, Inc., USA) with colectors (4,000 cm^2) in forest stands.

In an experimental watershed at Lomnistá dolina, designed with focus on the assessment of the water functions of forests, the spatial variability of rainfall in the open area within the catchment area and precipitation variability of throughfall precipitation in forest ecosystems have been assessed. Fig. 1 shows

Table 1. Basic site characteristics of experimental plots for water balance measurements located at Poľana Mts. and Western Tatras Mts.

	Poľana Mts.	Western Tatras Mts.
Site location	Hukavský grúň	Červenec
Altitude (m a.s.l.)	850–900	1,420
Tree age (yr)	90–110	110
Tree species	Norway spruce, fir, beech	Norway spruce
Geology	volcanic	crystalline and mesozoic rocks with limestone
Soil type	cambisol	cambisols, rankers and lithosols

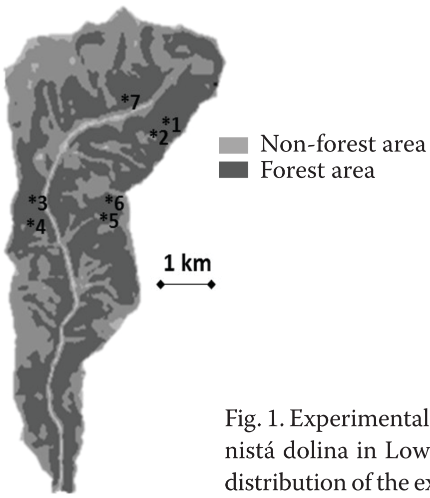

Fig. 1. Experimental catchment Lomnistá dolina in Low Tatras Mts. and distribution of the experimental plots

Table 2. Basic site characteristics of the experimental plots for precipitation mesurements located at the experimental catchment Lomnistá dolina in Low Tatras Mts.

Experimental plot	Altitude (m a.s.l.)	Exposure	Stand	
			density	age (yr)
1	1,450	NW	0.3	110
2	1,500	WNW	0.2	130
3	1,090	S	1.0	90
4	1,070	E	1.0	30
5	1,150	W	0.8	90
6	1,100	W	1.0	40
7	1,250	SE	0.9	70

the spatial distribution of the experimental plots with precipitation measurements and Table 2 summarizes the basic site characteristics of the plots.

Precipitation totals were measured by Hellman rain gauges (Thies Clima, Germany) – collecting area of 200 cm^2 – placed in an open area and in the forest stands (7 rain gauges per plot). The measurements were carried out at 14 days intervals.

RESULTS AND DISCUSSION

Interception loss and tree species composition

It is well known that the species composition significantly determines the value of intercept stormwater capture the crown layer, in view of the different structures and arrangements of crowns character assimilation apparatus. The biggest differences in the temperate zone is observed between softwoods and hardwoods (Kantor 1983).

Impact of tree species on rainfall interception throughfall was evaluated both within mixtured stand, and between other stands with a distinct species composition.

Total precipitation (open area) over the 10-year period were in the range of 799 to 1,158 mm. The rainfall precipitation represents about 70–80% from the total annual precipitation, the rest is snowfall. The annual total throughfall precipitation in mixtured stand ranged from 595 to 906 mm, which represented 70.6 to 85.7% of total precipitation above the forest canopy. The lowest interception calculated from the throughfall precipitation was 14.3%, the highest 29.4% (Table 3). Beech trees with their stemflow reduce interception losses to values in the range of 10.6 to 23.5% (Table 3). A more detailed analysis of selected interception set by rain gauges of tree species showed that the interception of spruce in mixtured stand is relatively balanced (30–33%) and fluctuations in overall throughfall precipitation are mainly connected with the fluctuations in the beech part of the mixtured stand. This is mainly due to a share of rain fallen during the growing season in a state of full foliage beech trees. The percentage of precipitation fallen during the growing season (in a state of full foliage beech) varies within a wide range from 48 up to 64%, which largely affects the resulting of total interception.

Table 3. Intervals of annual interception loss (%) for mature forest stands – Poľana Mts. (850 m a.s.l.), 10-year measurements

	TF		TF + SF	
	minimum	maximum	minimum	maximum
Spruce, fir, beech	14.3	29.4	10.6	23.5
Norway spruce	20.5	35.5	20.5	35.5
Beech	18.1	34.6	8.8	26.9

TF – throughfall precipitation, SF – stemflow

The results presented in Table 3 clearly show of the differences among interception processes in stands with different tree species composition. The highest interception loss values recognized the spruce stand (maximum up to 35.5%), somewhat lower values were measured in the beech stand (maximum 34.6%) and lowest interception losses showed a mixtured stand (maximum 34.6%). These values of interception are related to the values of throughfall precipitation. Taking into account the value of stemflow, the total value of interception losses reduced in the case of mixtured stands about 5–7% and for beech stands by 6–10%. Spruce stand has negligible value of stemflow, therefore only throughfall values are taken into account.

Interception loss and horizontal precipitation

Presence of fog/cloud precipitation has strong influence on interception loss during rainfall event. In case, that income of occult precipitation is large enough, net precipitation in forest can exceed precipitation recorded in open area (Krečmer 1968; Gabriel, Jauze 2008; Oreňák et al. 2013). Fig. 2 shows the mean interception loss in living and dead forest recorded in research plot Červenec in Western Tatras Mts. Presence of occult precipitation was derived from two indicators: throughfall precipitation in stands was higher than precipitation

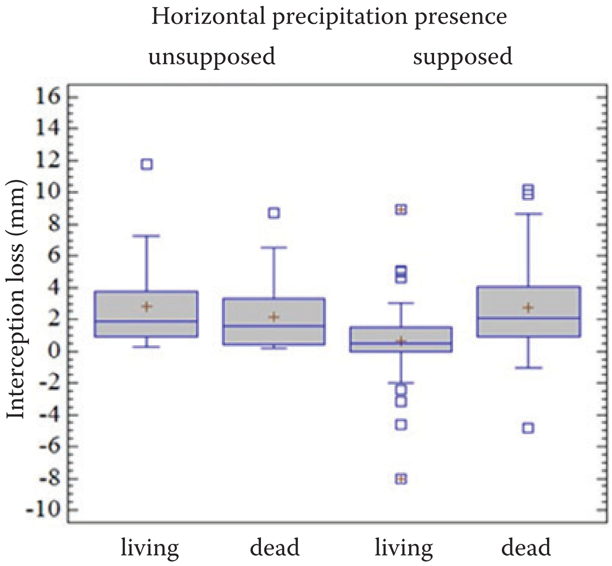

Fig. 2. Mean values and multiple box statistics of interception loss in living and dead forest with and without horizontal precipitation recorded in research plot Červenec in Western Tatras Mts.

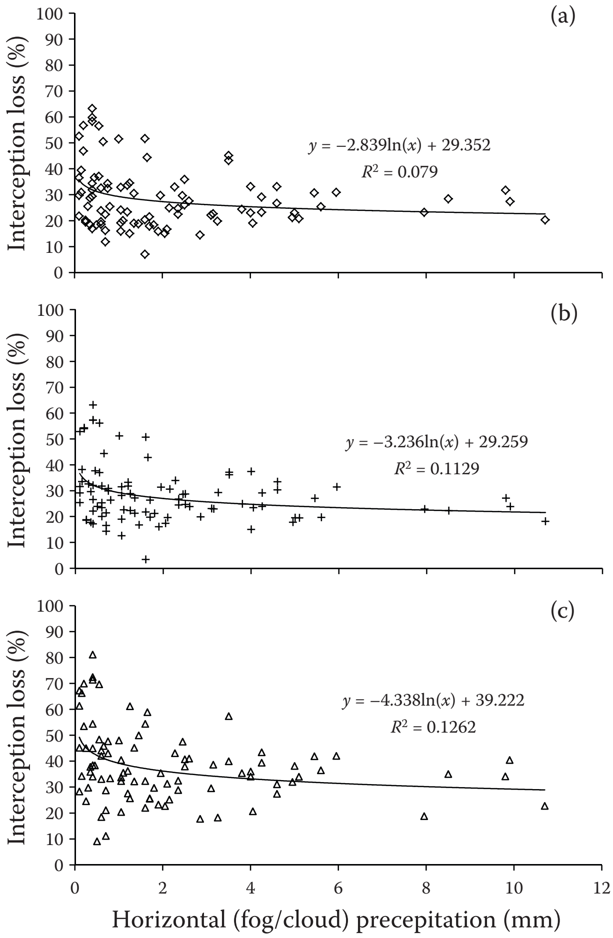

Fig. 3. Relationship between interception loss (throughfall) and horizontal (fog/cloud) precipitation amounts for three mature forest stands at Poľana Mts. (850 m a.s.l.) – 5-year measurements: Norway spruce + fir + beech (a), Norway spruce (b), beech (c)

in open area and/or throughfall precipitation in dead forest was higher than throughfall precipitation in living forest.

Differences of interception loss between dead and living forest was statistically significant ($\alpha < 0.001$) in both cases (with/without occult precipitation, Wilcoxon and Student paired test was used). Mean interception loss during rainfall event without supposed occult precipitation (Ø gross precipitation 5.4 mm) was 52.2% (2.82 mm) in living and 40.4% (2.18 mm) in dead forest. In case of a rainfall event with supposed fog precipitation mean interception loss was 7.2% (0.63 mm) in the living and 31.2% (2.71 mm) in the dead forest.

The impact of horizontal precipitation on interception of throughfall precipitation (only for rainy season) was also analyzed for three mature forest stands: mixtured, spruce and beech at Poľana Mts. The results are presented in Fig. 3. In all three stands a decrease in interception of throughfall precipitation was observed and a statistically significant relation ($\alpha < 0.01$, Student t-test of the significance of the regression model) was identified for mixtured and spruce stands. Coniferous trees (especially Norway spruce) with their crown structure and high surface potential of the needle are "more effective" in capturing fog droplets than deciduous trees (Krečmer et al. 1979).

The occurrence of horizontal precipitation in this area reduces the long-term average of interception loss (throughfall) by 3.2% (mixtured and spruce stands) and 2.9% for beech forest.

Interception loss and forest structure

Interception losses in forest stands are variable. Fig. 4 shows the mean value of interception losses recorded in biweekly intervals during vegetation period (May–October) in years 2013 and 2014. Net precipitations were monitored in three different places in living and dead forest: in a canopy gap, in a dripping zone under crown periphery and in a central crown zone near the stem.

The highest mean interception losses were observed in the central crown zone near the stem (in living forest 76.9% and dead forest 69.2%). The most variable interception losses are in dripping zone under crown periphery (in living forest from −47.9 to 85.7%, in dead forest from −55.5 to 57%). Mean interception in this place was in dead 25.7% and 11.1% in living forest. In canopy gap (free area in forest for 1–2 crowns) mean interception was 17.9% in dead and 11.7% in living forest.

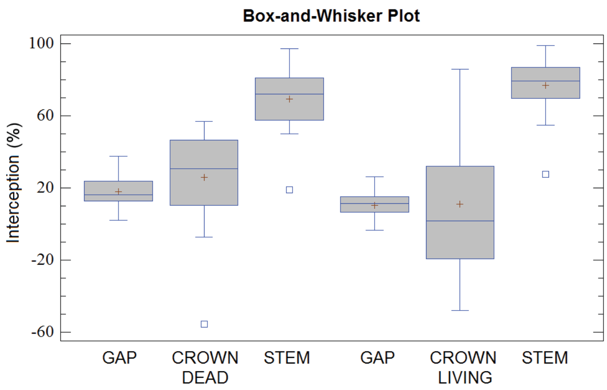

Fig. 4. Mean interception loss in three different zones in living and dead forest: in canopy gap (GAP), in dripping zone under crown periphery (CROWN) and in central crown zone near the stem (STEM) in research plot Červenec in Western Tatras Mts.

Table 4. Results of regression analysis of interception for different parts of mixtured stands (Hukavský grúň, Poľana Mts.) – 10-year measurements

	Linear regression	Canopy storage capacity (mm)	R^2
Canopy gap	0.849 × TP – 1.2	1.2	0.979
Beech part	0.782 × TP – 1.7	1.7	0.984
Spruce part	0.737 × TP – 2.5	2.5	0.964
Mixtured forest	0.807 × TP – 2.1	2.1	0.985

TP – precipitation totals in an open area (mm), R^2 – coefficient of determination

We compared the same locality in dead and living forest. In all cases a statistically significant difference was proved ($\alpha < 0.05$). High interception losses in dead forest can by due to massive presence of lichen *Pseudevernia furfuracea* (Linnaeus) Zopf, which covered branches of standing dead trees. Lowest mean interception loss was recorded in the dripping zone under crown periphery in the living forest. Captured precipitation in canopy layer is leading due canopy architecture in the crown periphery. Other potential reason is rich net precipitation in this locality is capturing of occult/fog precipitation. Oreňák et al. (2013) present mean interception during years 2007–2011 in living forest 27% in canopy gap, 20% in dripping zone under crown periphery and 63% in central crown zone near the stem, Holko et al. (2009) present mean interception in the same localities 28, 44 and 65%, what declare large yearly variance.

To determine the impact of the structure of mixtured forest (Hukavský grúň, Poľana Mts.) to stand interception we extracted the individual data of rain gauges in different parts of the stand (canopy gaps, spruce trees and beech trees) to compare the differences in throughfall precipitation and interception impact of different tree species. The Table 4 presents the calculations by regression of precipitation between the open area and throughfall specifically for crown gap portion beech and spruce section. The lowest values of initial canopy storage are achieved in canopy gap (1.2 mm). A little higher canopy storage capacity represents beech parts (1.7 mm) and a maximum value is related to spruce parts (2.5 mm). For all mixtured stand is canopy storage capacity of 2.1 mm, therefore can be conclude that the admixture of spruce in mixtured stands increases the values of canopy storage capacity for precipitation.

Interception loss and rainfall intensity

Dependence of interception losses in relation to the rainfall intensity was evaluated on a 6-year set of precipitation measurements in the area of Poľana Mts. for three types of forest ecosystems: (*i*) mixtured (fir, spruce, and beech), (*ii*) Norway spruce, (*iii*) beech mature forest stands. Relationship between the rainfall intensity above tree canopy and percentage of interception loss was expressed by the regression equations (Fig. 5).

In all cases interception decreases with increasing rainfall intensity. The highest negative slope of the line occurred on the Norway spruce stand, with a decrease of about 20% of interception to 1 mm·min^{-1} of vertical rainfall intensity. Mixtured forest stand was only slightly lower and beech stand was 50% lower than on spruce stand. The largest decline was in values interception intensity values of 1 mm·min^{-1}. This value has already decreased only very slight.

The significance of sample correlation coefficients was tested at the 0.01 (99%) level, in which we found that the differences between mixtured and spruce stands are statistically significant, for the beech forests, the significance at this level has not been confirmed.

Assessment of the impact of rainfall intensity on the interception loss is still not clear corresponding to literature. Rutter (1976) evaluated the dependence of interception losses in relation to the potential evaporation for different intensities of rainfall in the range of 0.4 to 2.0 mm·h^{-1} with two modes of precipitation: continuous (prolonged) and short-term (intermittent). These results showed that the higher rainfall intensity increases the interception loss especially for short-term (intermittent) rainfall events.

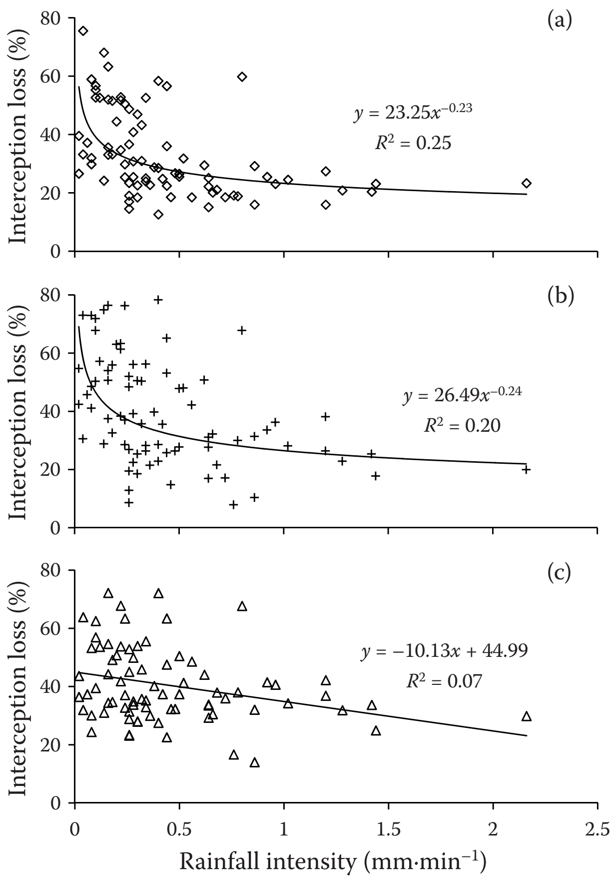

Fig. 5. Relationship between interception loss and rainfall intensity for three mature forest stands at Poľana Mts. (850 m a.s.l.): Norway spruce + fir + beech (a), Norway spruce (b), beech (c)

Tallaksen et al. (1996) made a comparative study of experimental interception measurements in spruce stands with three selected models to calculate the interception: HBV Nordic model, Amor model and simple Rutter model. Based on direct measurements and model calculations, the authors did not find a greater dependence on the rainfal intensity. However, the results published by Hörmann et al. (1996) indicate that a key role in this regard can play the wind. Measurement results of interception loss and interception capacity of a 97-year-old beech stand in northern Germany showed a significant dependence of interception capacity and wind speed, which has the power law shape. For wind speeds of around 2 $m \cdot s^{-1}$ amounted to intercept capacity crowns beech stand a value of about 2.5 mm, at a speed of 8 $m \cdot s^{-1}$, it was only 0.5 mm (Hörmann et al. 1996). If we realize that the highest intensity of precipitation for the area Poľana – Hukavský grúň occur almost exclusively in connection with the storm rainfall from convective clouds, which leads to amplification of wind speed (squall), this fact might to some extent explain our results.

The importance of wind and higher energy of rainfall droplets associated with the higher intensity confirmed by other authors, who also measured decrease in interception losses with increasing of rainfall intensity (Ramírez, Senarath 2000; Markart et al. 2007; Reid, Lewis 2009; López-Lambrano et al. 2013). These results were also confirmed by experimental measurements based on an artificial forest (Toba, Ohta 2008). Schulze et al. (1978) for 10 years old forest stand found the opposite dependence e.g. increase interception with increasing of rainfall intensity.

The results of rainfall simulation experiments for eight tested species give quantitative estimates of how storage varies by rainfall intensity. Incremental storage gains decreased as rainfall intensity increased. Interception processes are controlled by a conceptual mechanical model of canopy storage during rainfall that includes the concepts of static storage and dynamic storage to account for intensity-driven changes in storage (Keim et al. 2006).

These contradictory results may be associated with the multifactorial impact of landscape structure, forest structure and meteorological conditions at particular rainfall events.

Precipitation and interception loss – spatial variability in catchment

Atmospheric precipitation is the most important input parameter in the water balance of the landscape and their regime fundamentally determines the hydrological runoff. That is the reason why we pay attention to study the precipitation regime in an experimental watershed, both in terms of their spatial distribution as well as of their influencing by forest ecosytems.

The first step was to evaluate the variability of precipitation measured in an open area in tracing comparison precipitation totals obtained from the nearest meteorological station with rainfall totals (station Jasenie is about 4 km to south from the beginning of the catchment) from measurements in the experimental catchment Lomnistá dolina for each plot separately using regression and correlation analysis. Rainfall totals from Jasenie (Precipitation station of the Slovak Hydrometeorological Institute – SHMI) had to be converted to the corresponding period of measurements on individual research plots and analyzed to precipitation data from the catchment (Table 5).

For better illustration of the variability of individual rainfall events within the catchment, the com-

Table 5. Funcionality of precipitation totals for precipitation station Jasenie (Slovak Hydrometeorological Institute) and individual research plots in experimental catchment Lomnistá dolina

Experimental plot	Linear regression	R^2
1	$y = 1.64 \times x + 6.8$	0.794
3	$y = 1.46 \times x + 1.7$	0.983
5	$y = 1.62 \times x + 0.6$	0.985
6	$y = 1.08 \times x + 8.1$	0.933
7	$y = 2.22 \times x + 4.5$	0.659

x – rainfall totals (mm) from the Jasenie meteorological station, R^2 – coefficient of determination

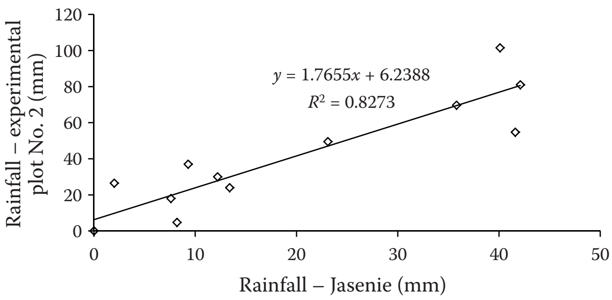

Fig. 6. Comparison of rainfall events between experimental plot No. 2 (Lomnistá dolina, 1,500 m a.s.l.) and meteorological station Jasenie (490 m a.s.l.) in period 01.05.–31.10.2000

parison of individual rainfall events between experimental plot No. 2 (Lomnistá dolina, 1,500 m a.s.l.) and meteorological station Jasenie (490 m a.s.l.) in period 01.05.–31.10.2000 is presented in Fig. 6.

The next step was to verify the significance of the differences between precipitation totals of the closest precipitation stations (Jasenie) as well as with each experimental site, using statistical paired *t*-test. The results confirmed the very high statistically significant difference between the amount of precipitation from Jasenie (SHMI) and all research plots in the area of interest.

The statistical significance of differences in total precipitation generally decreased proportionally with the diminishing differences in altitude. It follows that variability at source field for individual rainfall events is significant and certainly can not be represented by precipitation stations lying outside the field of mountain forests – basin mountain streams (Lančarič et al. 2001).

In terms of interception losses, we investigated the value of the total interception in individual areas in relation to the characteristics of individual stands, as well as the overall variability of throughfall precipitation totals. Summary results are presented in Table 6.

Table 6. Interception loss (throughfall) during the growing seasons measured at individual research plots in experimental catchment Lomnistá dolina – 3-year measurements

Experimental plot	Interception loss (%)	Altitude (m a.s.l.)
1	18.6	1,450
2	26.1	1,500
3	**41.7**	1,090
4	28.8	1,070
5	37.2	1,150
6	**–10.2**	1,100
7	38.9	1,250

maximum and minimum value (interception loss) in bold

Higher value interception loss at experimental plot 1 compared plot 2 is due to the stand density and canopy structure. On the other research areas to meet the prerequisites of interception loss reduction with an increase in altitude. Special case is the experimental plot 6, in which the result of interception process was –10.18% compared to the open area, what means that throughfall precipitation were higher than open field precipitation. Tree species composition (Norway spruce – 100%) and stand density (1.0) together with west exposure and mountain ridge location can bring the precipitation profit caused by capture of horizontal precipitation. The interception values were tested by a statistical paired *t*-test of the hypothesis of equality of arithmetic means. We tested the differences in values interception in all research areas. The main differences ($\alpha < 0.01$) were identified for canopy structure, altitude and exposure.

In terms of the total variability in rainfall spatial distribution needs to be noted that the precipitation transition proces through the forest canopy means further variability increases as compared with the primary pecipitation field variability in an open area (Vertessy et al. 2001).

CONCLUSIONS

The results of precipitation monitoring in forest ecosystems of Slovakia has brought many stimulating knowledge. Area of mountain forests in Slovakia (above 800 m a.s.l.) is significant in terms of its hydrologic effects due to their distribution in the landscape with a positive water balance and structural biodiversity (Škvarenina et al. 2004; Hreško et al. 2015).

At present, the area of mountain forests is attacked by several negative factors such as insect pests, drought and emerging climate change (Ďurský et al. 2006; Kurjak et al. 2012; Mezei et al. 2014). All these factors can significantly affect the overall hydric effects of forests in quantity but also the quality of water runoff.

The presented results from several experimental plots documented mainly interception process in selected forest ecosystems affected by various factors. The main findings can be summarized as follows:

(*i*) Tree species composition of forest ecosystems significantly influence the entire interception of forest ecosystems where is a key ratio of coniferous and deciduous trees;

(*ii*) Forest stand structure significantly modifies the interception process, especially in the 7th altitudinal vegetation zone;

(*iii*) Forest ecosystems due to their tree species composition, stand density, stand age and spatial distribution increase the variability of rainfall infiltrated to the soil environment in mountain watersheds;

(*iv*) Intensity of rainfall entering to the forest ecosystem reduces somewhat interception losses which may mean an increased risk of surface runoff during the storm events;

(*v*) The impact of horizontal precipitation on interception process applies to the areas of occurrence of mountain advective fogs in the windward and ridge locations;

(*vi*) Precipitation stations outside from the mountain catchments cannot represent the precipitation distribution within the catchments.

References

Calder I., Hofer T., Vermont S., Warren P. (2007): Towards a new understanding of forests and water. Unasylva, 229: 3–10.

Chang M. (2013): Forest Hydrology: An Introduction to Water and Forests. 3rd Ed. Boca Raton, CRC Press: 569.

Ďurský J., Škvarenina J., Minďáš J., Miková A. (2006): Regional analysis of climate change impact on Norway spruce (*Picea abies* L. Karst.) growth in Slovak mountain forests. Journal of Forest Science, 5: 306–315.

Gabriel G., Jauze L. (2008): Fog water interception by *Sophora denudata* trees in a Reunion upper-montane forest, Indian Ocean. Atmospheric Research, 87: 338–351.

Gömöryová E., Střelcová K., Škvarenina J., Gömöry D. (2013): Responses of soil microorganisms and water content in forest floor horizons to environmental factors. European Journal of Soil Biology, 55: 71–76.

Holko L., Škvarenina J., Kostka Z., Frič M., Staroň J. (2009): Impact of spruce forest on rainfall interception and seasonal snow cover evolution in the Western Tatra Mountains, Slovakia. Biologia, 64: 594–599.

Hörmann G., Branding A., Clemen T., Herbst M., Hinrichs A., Thamm F. (1996): Calculation and simulation of wind controlled canopy interception of a beech forest in Northern Germany. Agriculture and Forest Meteorology, 79: 131–148.

Hreško J., Petrovič F., Mišovičová R. (2015): Mountain landscape archetypes of the Western Carpathians (Slovakia). Biodiversity and Conservation, 24: 3269–3283.

Hríbik M., Vida T., Škvarenina J., Škvareninová J., Ivan L. (2012): Hydrological effects of Norway spruce and European beech on snow cover in a mid-mountain region of the Polana Mts., Slovakia. Journal of Hydrology and Hydromechanics, 60: 319–332.

Kantor P. (1983): Intercepční ztráty smrkových a bukových porostů. Vodohospodársky časopis, 31: 643–651.

Keim R.F., Skaugset A.E., Weiler M. (2006): Storage of water on vegetation under simulated rainfall of varying intensity. Advances in Water Resources, 29: 974–986.

Krečmer V. (1968): K intercepci srážek ve středohorské smrčině. Opera Corcontica, 5: 83–96.

Krečmer V., Fojt V., Křeček J. (1979): Horizontální srážky z mlhy v lesích jako položka vodní bilance v horské krajině. Meteorologické zprávy, 32: 78–81.

Kurjak D., Střelcová K., Ditmarová L., Priwitzer T., Homolák M., Pichler V. (2012): Physiological response of irrigated and non-irrigated Norway spruce trees as a consequence of drought in field conditions. European Journal of Forest Research, 131: 1737–1746.

Lančarič P., Minďáš J., Škvarenina J. (2001): Forest stand interception in mountain catchment in the Low Tatras. In: Weather Extremes as a Limiting Factor of Biometeorological Processes. International Bioclimatological Workshop, Račková dolina, Sept 10–12, 2001: 42–48.

Levia D.F., Carlyle-Moses D., Tanaka T. (eds) (2011): Forest Hydrology and Biogeochemistry: Synthesis of Past Research and Future Directions. Dordrecht, Springer Netherlands: 740.

López-Lambrano A., Fuentes C., González-Sosa E., Ramos A.L., Pliego-Díaz M., Gómez-Meléndez D., Altamirano-Corro A. (2013): Effect of interception by canopy in the intensity-duration-frequency relationships (IDF) relation (rainfall intensity, duration and frequency) in a semiarid zone. African Journal of Agricultural Research, 8: 5289–5299.

Markart G., Kohl B., Perzl F. (2007): Der Bergwald und seine hydrologische Wirkung – eine unterschätzte Größe? LWF Wissen No. 55: 34–43.

Mezei P., Grodzki W., Blaženec M., Škvarenina J., Brandýsová V., Jakuš R. (2014): Host and site factors affecting tree mortality caused by the spruce bark beetle (*Ips typographus*) in mountainous conditions. Forest Ecology and Management, 331: 196–207.

Minďáš J. (2003): Charakteristika snehových pomerov v lesných porastoch stredohorskej oblasti Poľana. Lesnícky časopis – Forestry Journal, 49: 105–115.

Minďáš J., Škvarenina J. (1995): Chemical composition of fog/cloud and rain/snow water in Biosphere Reserve Poľana, Slovakia. Ekológia (Bratislava), 14: 125–137.

Minďáš J., Škvarenina J. (eds) (2010): Lesy Slovenska a voda. Zvolen, EFRA, Skalica, Stredoeurópska vysoká škola v Skalici, Zvolen, Technical University in Zvolen: 129.

Oreňák M., Vido J., Hríbik M., Bartík M., Jakuš R., Škvarenina J. (2013): Intercepčný proces smrekového porastu vo fáze rozpadu v Západných Tatrách. Zprávy lesnického výzkumu, 58: 360–369.

Ramírez J.A., Senarath S.U.S. (2000): A statistical-dynamical parameterization of interception and land surface-atmosphere interactions. Journal of Climate, 13: 4050–4063.

Reid L.M., Lewis J. (2009): Rates, timing, and mechanisms of rainfall interception loss in a coastal redwood forest. Journal of Hydrology, 375: 459–470.

Rutter A.J. (1976): The hydrological cycle in vegetation. In: Monteith J.L. (ed.): Vegetation and the Atmosphere. London, Academic Press: 111–154.

Schulze R.E., Scott-Shaw C.R., Nänni U.W. (1978): Interception by *Pinus patula* in relation to rainfall parameters. Journal of Hydrology, 36: 393–396.

Škvarenina J., Križová E., Tomlain J. (2004): Impact of the climate change on the water balance of altitudinal vegetation stages in Slovakia. Ekológia (Bratislava), 23: 13–29.

Střelcová K., Minďáš J., Škvarenina J. (2006): Influence of tree transpiration on mass water balance of mixed mountain forests of the West Carpathians. Biologia, 61 (Supplement 19): S305–S310.

Tallaksen L.M., Schunselaar S., van Veen R. (1996): Comparative model estimates of interception loss in a coniferous forest stand. Nordic Hydrology, 27: 143–160.

Toba T., Ohta T. (2008): Factors affecting rainfall interception determined by a forest simulator and numerical model. Hydrological Processes, 22: 2634–2643.

Vertessy R.A., Watson F.G.R., O'Sullivan S.K. (2001): Factors determining relations between stand age and catchment water balance in mountain ash forests. Forest Ecology and Management, 143: 13–26.

Vyskot I., Kapounek L., Krešl J., Kupec P., Macků J., Rožnovský J., Schneider J., Smítka D., Špaček F., Volný S. (2003): Quantification and Evaluation of Forest Functions on the Example of the Czech Republic. Prague, Ministry of the Environment of the Czech Republic: 218.

Received for publication May 16, 2018
Accepted after corrections August 28, 2018