DENDROBIOLOGY
2004, vol. 51, Supplement 27–34

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Water-management role of Norway spruce *Picea abies* (L.) Karst. and European beech *Fagus sylvatica* L. in mountain locations

Abstract: All basic components of the water budget of a mature spruce and beech stand in the Orlické Mts are quantified and the results are given in summary tables. Rest periods (November–April) and vegetation seasons (May–October) are evaluated separately. Special attention is paid to the measurement of snow cover and the processes of snow melting in both types of stands.

Additional key words: water budget, precipitation, summary evaporation, runoff, snow cover

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Introduction

The area of the Czech Republic is divided into 41 forest regions. These are the largest territorial units of forests having identical geographical, climatic, orographic and natural conditions. From these units, nine can be described as mountain forest regions occurring at altitudes from about 700 to 1300 m. As for the species composition of forests, spruce markedly dominates and beech accounts for the largest proportion of broadleaved species.

Forest region 40 – the Moravian-Silesian Beskids – does not rank among the largest regions as for its area (63 000 ha), however, with respect to its production potential and actual growing stock, forests of the Beskids occupy an exceptional position within the whole Czech Republic. From the total area of forests, 73% represent conifers with a major proportion of Norway spruce – about 70%. The remaining 27% of the area is covered by broadleaves, in the first place beech.

In addition to the important position as a permanent source of wood production, forest ecosystems of the Beskids, like all Czech mountain forest regions with a high supply of atmospheric precipitation, fulfil also social needs by performing a water-management role. The role includes both a quantitative and a qualitative component. The quantitative water-management function answers the question “how much” water drains from the forest. The qualitative water-management function assesses not only “what kind of water” runs off from the forest but particularly “how” the water runs off. In other words, forest ecosystems are evaluated from the viewpoint of runoff distribution in time, runoff balance and flood control.

Water-management research into forests shows a long-term and uninterrupted tradition just in the Beskids (Mařan and Lhota 1952; Zelený 1971; 1974, Jařabáč and Chlebek 1988, 1996). At present, there is e.g. nearly a 50-year series of observations in two experimental watersheds – Malá Ráztoka (with the dominance of beech) and Červík (with dominating spruce). Since the hydrological year 1953/1954, the basic components of the water budget have been studied (precipitation, summary evaporation, runoff) in both closed partial watersheds. In the calibration period, the following basic results were obtained:

- Červík (spruce): precipitation 1080 mm, evaporation 476 mm (44%), runoff 604 mm (56%),

– Malá Ráztoka (beech): precipitation 1250 mm, evaporation 433 mm (35%), runoff 817 mm (65%).

General ideas on the basic components of the water balance of spruce (or beech) in mountain locations can be obtained particularly from German studies (see Table 1).

Experimental area and methods

With respect to the topical character of water-management problems in the Czech Republic and the need to obtain actual exact data, a permanent research field station was established in 1976 in another forest region, viz. in the Orlické Mts.

The aim of research is to assess and compare the water-management effectiveness and all components of the water budget of two main species of mountain locations, viz. spruce *Picea abies* (L.) Karst. and beech *Fagus sylvatica* L. Research plots were established in 1976 in a mature spruce and a mature beech stand in the cadaster of Deštné (coordinates: 50°19'20" N and 16°21'45" E). Both stands are uniform from typological and pedological aspects, being situated in the immediate proximity on the slope of WSW aspect with a mean gradient of 30% at an altitude of 900 m. In winter 1982, both mature stands were cut down and the originated clear-felled areas were immediately artificially regenerated again by spruce and beech. The study of water balance in these newly established stands is carried out in the same way as in the original mature stands. At present, a continuos 26-year series is available of comparative examinations of the water budget of spruce and beech ecosystems (5-year calibration series in mature stands, 21-year time series in newly established stands).

Methodological procedures of measurements were published in detail in a number of papers, e.g. in the scientific forest journal Lesnictví (Kantor 1984, 1992, 1995). We can state here that the open area precipitation is continuously studied and evaluated together with all basic components of the water balance of both species: interception losses, soil surface evaporation, ground vegetation evapotranspiration, surface runoff, horizontal subsurface runoff, vertical seepage, soil moisture, snow cover parameters and snow melting processes, air temperature and relative humidity. Only tree species transpiration is not determined experimentally but is calculated as a sole unknown quantity from the equation of water balance.

The present paper assesses and evaluates particularly the 'calibration period', i.e. the water budget of mature stands in 1976 to 1981.

Results and discussion

Basic data on particular components of the water balance in hydrological years 1976/1977 to 1980/1981 and in vegetation and rest periods of the years are given in Tables 2, 3 and 4.

Open area precipitation

From the viewpoint of the total amount of annual atmospheric precipitation, the evaluated hydrological years 1976/1977 to 1980/1981 can be considered as normal for the region of the Orlické Mts and the given altitude of 900 m. Maximum precipitation, viz. 1500.0 mm, was recorded in 1979/1980, minimum precipitation, viz. 1071.0 mm, in 1978/1979. On average, the annual precipitation of the open area reached a value of 1296.4 mm in the period under study. Of the figure, the rest period amounted to 569.3 mm (43.9%) and the vegetation season to 727.1 mm (56.1%).

Table 1. Water balance of mountain spruce and beech stands according to various studies

Author Study region	Precipitation open area	Spruce		Beech	
		total evaporation	runoff	total evaporation	runoff
Brechtel and Balázs (1980)				564 mm	186 mm
FRG, Hann. Münden	750 mm			75%	25%
Kirwald (1974)		472 mm	555 mm		
FRG, Ruhr watershed	1027 mm	46%	54%		
Benecke and van der Ploeg (1978)		616 mm	450 mm	515 mm	551 mm
FRG, Solling	1066 mm	58%	42%	48%	52%
Van der Ploeg (1978)		455 mm	615 mm		
FRG, Lange Bramke	1070 mm	43%	57%		
Ambros (1978)		550 mm	550 mm	451 mm	649 mm
Slovakia, Carpathians	1100 mm	50%	50%	41%	59%
Delfs et al. (1958)		576 mm	677 mm		
FRG, Lange Bramke	1253 mm	46%	54%		

Table 2. Water balance of spruce and beech stands in hydrological years 1976/1977–1980/1981 (Orlické Mts)

Hydrological year	Precipitation open area	Interception		Transpiration		Evaporation		Surface runoff		Horizontal runoff through soil		Seepage to bedrock		± Soil moisture	
	mm	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
Spruce stand															
1976/1977	1263.6	190.4	15.1	234.2	18.5	84.8	6.7	2.4	0.2	11.4	0.9	743.3	58.8	–2.9	–0.2
1977/1978	1187.0	192.3	16.2	199.9	16.8	74.5	6.3	11.5	1.0	22.7	1.9	670.2	56.5	15.9	1.3
1978/1979	1071.0	226.3	21.1	165.1	15.4	97.5	9.1	19.3	1.8	21.2	2.0	546.0	51.0	–4.4	–0.4
1979/1980	1500.0	264.3	17.6	184.2	12.3	62.3	4.2	13.9	0.9	24.1	1.6	944.8	63.0	6.4	0.4
1980/1981	1460.5	187.4	12.8	192.3	13.2	82.1	5.6	17.0	1.2	15.4	1.1	961.3	65.8	5.0	0.3
Mean	1296.4	212.1	16.3	195.2	15.1	80.2	6.2	12.8	1.0	19.0	1.5	773.1	59.6	4.0	0.3
Beech stand															
1976/1977	1263.6	73.0	5.8	202.2	16.0	82.4	6.5	20.3	1.6	14.8	1.2	872.8	69.1	–1.9	–0.2
1977/1978	1187.0	54.7	4.6	175.0	14.7	73.4	6.2	18.0	1.5	18.2	1.5	843.4	71.1	4.3	0.4
1978/1979	1071.0	92.4	8.6	160.7	15.0	90.6	8.5	14.1	1.3	13.5	1.3	698.8	65.2	0.9	0.1
1979/1980	1500.0	102.9	6.9	173.7	11.6	54.6	3.6	29.3	2.0	27.6	1.8	1108.9	73.9	3.0	0.2
1980/1981	1460.5	110.3	7.6	192.4	13.2	82.8	5.7	25.4	1.7	26.8	1.8	1019.1	69.8	3.7	0.2
Mean	1296.4	86.6	6.7	180.8	13.9	76.8	5.9	21.4	1.6	20.2	1.6	908.6	70.1	2.0	0.2

Table 3. Water balance of spruce and beech stands in rest periods (1 November – 30 April) (Orlické Mts)

Rest period	Precipitation open area	Interception		Transpiration		Evaporation		Surface runoff		Horizontal runoff through soil		Seepage to bedrock		± Soil moisture	
	mm	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
Spruce stand															
1976/1977	579.8	57.0	9.8	27.1	4.7	6.7	1.2	2.0	0.3	7.2	1.2	472.9	81.6	6.9	1.2
1977/1978	449.7	62.8	14.0	12.6	2.8	4.3	0.9	4.0	0.9	7.8	1.7	340.3	75.7	17.9	4.0
1978/1979	557.6	89.9	16.1	13.2	2.4	3.5	0.6	12.8	2.3	6.2	1.1	428.3	76.8	3.7	0.7
1979/1980	618.5	84.2	13.6	4.7	0.8	1.8	0.3	12.7	2.0	18.5	3.0	490.2	79.3	6.4	1.0
1980/1981	641.0	16.2	2.5	6.5	1.0	6.9	1.1	15.3	2.4	12.2	1.9	575.7	89.3	8.2	1.3
Mean	569.3	62.0	10.9	12.8	2.2	4.6	0.8	9.4	1.7	10.4	1.8	461.5	81.1	8.6	1.5
Beech stand															
1976/1977	579.8	22.3	3.9	7.5	1.3	5.4	0.9	10.6	1.8	8.7	1.5	519.7	89.6	5.6	1.0
1977/1978	449.7	22.9	5.1	5.5	1.2	5.8	1.3	9.7	2.1	9.3	2.1	396.5	88.2	–	–
1978/1979	557.6	25.3	4.5	4.5	0.8	2.9	0.5	10.3	1.8	10.4	1.9	493.8	88.6	10.4	1.9
1979/1980	618.5	41.6	6.7	1.0	0.2	1.6	0.2	16.1	2.6	15.3	2.5	536.1	86.7	6.8	1.1
1980/1981	641.0	38.5	6.0	3.8	0.6	8.1	1.3	16.2	2.5	20.0	3.1	549.6	85.7	4.8	0.8
Mean	569.3	30.1	5.3	4.5	0.8	4.8	0.8	12.6	2.2	12.7	2.2	499.1	87.7	5.5	1.0

Table 4. Water balance of spruce and beech stands in vegetation seasons (1 May – 31 October) (Orlické Mts

Vegetation Season	Precipitation open area	Interception		Transpiration		Evaporation		Surface runoff		Horizontal runoff through soil		Seepage to bedrock		± Soil moisture	
	mm	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
						Spruce stand									
1977	683.8	133.4	19.5	207.1	30.3	78.1	11.4	0.4	0.1	4.2	0.6	270.4	39.5	–9.8	–1.4
1978	737.3	129.5	17.6	187.3	25.4	70.2	9.5	7.5	1.0	14.9	2.0	329.9	44.8	–2.0	–0.3
1979	513.4	136.4	26.6	151.9	29.6	94.0	18.3	6.5	1.3	15.0	2.9	117.7	22.9	–8.1	–1.6
1980	881.5	180.1	20.4	179.5	20.4	60.5	6.9	1.2	0.1	5.6	0.6	454.6	51.6	–	–
1981	819.5	171.2	20.9	185.8	22.7	75.2	9.2	1.7	0.2	3.2	0.4	385.6	47.0	–3.2	–0.4
Mean	727.1	150.1	20.6	182.4	25.1	75.6	10.4	3.4	0.5	8.6	1.2	311.6	42.8	–4.6	–0.6
						Beech stand									
1977	683.8	50.7	7.4	194.7	28.5	77.0	11.3	9.7	1.4	6.1	0.9	353.1	51.6	–7.5	–1.1
1978	737.3	31.8	4.3	169.5	23.0	67.6	9.2	8.3	1.1	8.9	1.2	446.9	60.6	4.3	0.6
1979	513.4	67.1	13.1	156.2	30.4	87.7	17.1	3.8	0.7	3.1	0.6	205.0	39.9	–9.5	–1.8
1980	881.5	61.3	6.9	172.7	19.6	53.0	6.0	13.2	1.5	12.3	1.4	572.8	65.0	–3.8	–0.4
1981	819.5	71.8	8.8	188.6	23.0	74.7	9.1	9.2	1.1	6.8	0.8	469.5	57.3	–1.1	–0.1
Mean	727.1	56.5	7.8	176.3	24.3	72.0	9.9	8.8	1.2	7.5	1.0	409.5	56.3	–3.5	–0.5

Expenditure components of the water budget of a forest

Interception losses of the spruce and beech stands in individual hydrological years are compiled together with other items of the water balance in Table 2. While in the crowns of spruce trees, on average 212.1 mm (16.3%) of atmospheric precipitation were intercepted and later evaporated, the mean losses of beech amounted only to 86.6 mm (6.7% of annual precipitation). Thus, in the spruce stand, on average 83.7% of precipitation reached the soil surface, while in the beech stand it was 93.3%. The marked difference in the value of interception losses can be explained by the different character of the interception process in both compared species, particularly by the entirely different stemflow. The stemflow was nearly negligible in spruce, amounting to 1.5% of annual atmospheric precipitation only, whereas in beech it constituted an important 15.0-percent component in the water regime of the forest.

Based on a separate evaluation of rest and vegetation periods (Tables 3 and 4) it is evident that interception losses in both mountain stands are markedly lower from November to April (spruce 10.9%, beech 5.3%) than from May to October (spruce 20.6%, beech 7.8%) with respect to low temperatures and high air humidity.

The water budget of forests in mid-mountain locations can be markedly improved by horizontal precipitation. Thus, it is possible to interpret even relatively low interception values of both compared stands in the Orlické Mts. In winter periods, the occurrence of solid horizontal precipitation, i.e. hard rime, can decrease interception losses of conifer spruce stands to minimum values (in winter 1980/1981, spruce interception 2.5% only). In general, it is possible to say that horizontal precipitation improved the water balance of both spruce and beech stands in the Orlické Mts by 50 to 120 mm per year (5–10% precipitation).

Transpiration being in the rest half-year unimportant, represented the most important negative component of water balance in the vegetation season both in the spruce stand (on average 182.4 mm, i.e. 25.1% summer precipitation) and in the beech stand (176.3 mm, i.e. 24.3%). On experimental plots in the Orlické Mts, the spruce stand consumed for transpiration on average 195.2 mm water (15.1% precipitation) per year, the beech stand by 14.4 mm less, i.e. 180.8 mm (13.9%). Somewhat lower values of the physiological evaporation of beech can be explained by a shorter, 5-month vegetation season of the species (foliage unfolds usually in the course of May and falls in October). However, an assumption has been proved about unimportant transpiration differences between spruce and beech (Benecke and van der Ploeg 1978). The dispersion of transpiration values (Tables 2 and 4) is determined by climatic factors, particulary important of which are: precipitation regime, air temperature and humidity, solar radiation, wind, soil moisture dynamics, etc.

Soil surface evaporation + ground vegetation evapotranspiration are the last important negative component of the forest water budget. With respect to the small extent of the herb and grass layer (max. 20%), evaporation from the soil surface was substantially more important. In the winter half-year, evaporation was negligible with respect to the 4–5-month continuous occurrence of the snow cover. On the other hand, in the vegetation season, this item played a substantially more important role in the forest water regime. Like with transpiration, the values of evaporation from the soil surface are in close correlation with climatic factors. Thus, in the spruce stand, 94.0 mm water evaporated from the soil surface in the dry hot summer of 1979, in contrast, in the moist and cold summer period of 1980, evaporation amounted to 60.5 mm only. Similar values were also recorded in the beech stand (87.7 mm in summer 1979 and 53.0 mm only in 1980). As for the mean of five vegetation seasons under evaluation, soil surface evaporation including ground vegetation evapotranspiration amounted to 75.6 mm (10.4% summer precipitation) in the spruce stand water balance and to 72.0 mm (9.9%) in the beech stand.

Runoff

Atmospheric precipitation which is not consumed by forest stands for interception, transpiration and evaporation runs off after the replenishment of soil water supplies. The runoff regime appears to be one of the most important indicators of the hydric efficiency of forest stands, being the result of the 'management of forests with water'. In the balance plots, it usually divides into surface runoff, horizontal subsurface runoff and seepage with the subsequent groundwater runoff.

The surface runoff of precipitation water represents the undesirable form of runoff from forest stands. With respect to the considerable retention capacity of forest soils the surface runoff contributed to the water budget of mature stands only slightly both after long-term summer rainstorms (e.g. in July 1980, with precipitation amounting to 388.0 mm the surface runoff in the spruce stand was 1.0 mm only) and during the intensive spring melting of accumulated snow precipitation (in spring 1977, 0.3 mm only in spruce). The year-long values of the surface runoff fluctuated in the mature spruce stand between 2.4 and 19.3 mm (on average 12.8 mm, i.e. 1.0% annual precipitation) and in the beech stand between 14.1 and 29.3 mm (on average 21.4 mm, i.e. 1.6%). The finding that surface runoff can be negligible even in large clear-felled areas should be considered to be extraordinarily important. In our case, more than 2% of annual precipitation did not ever drain as surface runoff even immediately after felling. Thus, it has been proved that forest soil preserves its retention and retardation capacity even after clear felling forest stands on mountain slopes. To minimise surface runoff and thus subsequent erosion, it is important to observe efficient environmentally-friendly logging and timber transport technologies.

In the course of study periods, the horizontal subsurface runoff was also inconsiderable. The runoff averaged 19.0 mm (1.5% annual precipitation) per year in the spruce stand and 20.2 mm (1.6%) in the beech stand. In both stands, low values of this form of runoff can be attributed to the physical properties of soil. Even the surface character of the spruce root system did not increase the subsurface horizontal runoff. Thus, in light-textured loamy to sandy-loam soils with a substantial proportion of skeleton and non-capillary pores, the vertical seepage of water through soil markedly predominated.

The vertical seepage of atmospheric precipitation through soil with subsequent underground runoff is usually not only the most important form of runoff from forest stands but in mountain locations it represents (nearly always with respect to high atmospheric precipitation and considerable retention capacity of forest soils) even the most important component of the forest water budget. Moreover, all water which percolates through particular soil horizons to the parent rock can be termed as water available for runoff – thus it refers to an extraordinarily important water-management factor which shows a decisive effect on the landscape water regime.

In rest periods, the regime of the vertical seepage of precipitation waters has a specific character. It is affected particularly by snow accumulation, snow melting during temporary thaws and the intensive melting of snow supplies in spring months. In the course of five years under investigation, the major part of precipitation waters percolated to the bedrock in both compared stands from November to April: in the spruce stand on average 461.5 mm (81.1% precipitation), in the beech stand 499.1 mm (87.7%) – see Table 3. After conversion, these values for the winter period correspond to the mean specific seepage (and underground runoff) of 29.5 l s^{-1} km^{-2} in the spruce stand and 31.9 l s^{-1} km^{-2} in the beech stand.

In the period of snow cover accumulation (November–February), the quantity of seepage was not usually related to the amount of precipitation; the vertical seepage occurred in the course of the transition of warm fronts, during temporary thaws.

In the spruce stand, seepage to the bedrock in this period (on average 195.2 mm, i.e. 18.8 l s^{-1} km^{-2}) was demonstrably higher than in the beech stand (on average 149.4 mm, i.e. 14.4 l s^{-1} km^{-2}). Higher values for spruce can be attributed to the fact that particularly liquid precipitation seeping through the snow cover into unfrozen soil participated in the vertical seepage in November–February. Snow melting proper affected seepage only exceptionally in the period. With respect to the drips of melting snow from spruce crowns during temporary thaws, the total amount of liquid precipitation in the spruce stand was substantially higher than that in the beech stand. Thus, the vertical seepage of water through soil in the conifer stand at the beginning and in the mid-winter months was also more important.

The seepage of accumulated snow precipitation showed quite an extraordinary course in the period of spring thaws when during several days, up to 300 mm water seeped to the bedrock. Forest soils of both experimental stands were able to accumulate and safely drain off even these huge quantities of water. With respect to the markedly lower supplies of water in snow in the spruce stand, considerably smaller amounts of water (on average 266.3 mm, i.e. 50.5 l s^{-1} km^{-2}) seeped and drained through soil during the last two months of the rest period (March–April) as compared with the beech stand (on average 349.7 mm, i.e. 66.4 l s^{-1} km^{-2}).

In vegetation seasons, the values of vertical seepage are usually lower than those in rest periods with respect to the high summary evaporation of the forest being particularly in close correlation with the precipitation regime. Also soil moisture relations show considerable effects on seepage because precipitation percolates to the bedrock after saturating particular soil horizons only.

The relation of the quantity of seepage to the supply of atmospheric precipitation can be documented by using an analysis of the results in the vegetation seasons under evaluation. In the precipitation-subnormal summer half-year of 1979 (open area precipitation 513.4 mm), only 117.7 mm of water (22.9% precipitation; mean specific seepage 7.4 l s^{-1} km^{-2}) seeped in the spruce stand and 205.0 mm (39.9% precipitation; 12.9 l s^{-1} km^{-2}) in the beech stand. In contrast, in the precipitation-rich vegetation season of 1980 – precipitation 881.5 mm – seepage with subsequent underground runoff recorded in spruce amounted to 454.6 mm of water (51.6% precipitation; mean specific seepage 28.6 l s^{-1} km^{-2}) and in beech even to 572.8 mm (65.0% precipitation; 36.0 l s^{-1} km^{-2}). In the remaining years under evaluation, the sums of seepage ranged between these limiting values, and in the 5-year average, seepage in the vegetation season in the spruce stand amounted to 311.6 mm (42.6% summer precipitation; 19.6 l s^{-1} km^{-2}); in the beech stand it was nearly 100 mm more: 409.5 mm (56.3% precipitation; 25.8 l s^{-1} km^{-2}).

Based on the evaluation of the 5-year-long data from experimental plots in the Orlické Mts, it is evident that in the spruce stand, on average 773.1 mm of water seeped and drained in the underground form (59.6% open area precipitation; mean annual specific seepage 24.5 l s^{-1} km^{-2}); in the beech stand, markedly higher mean annual seepage was recorded, viz. 908.6 mm (70.1% precipitation; 28.8 l s^{-1} km^{-2}). Thus, the results of the study have proved clearly that the vertical seepage of precipitation waters represents by far the most essential component in the water balance of our mountain forests. Higher total values in beech (on annual average, by 135.5 mm, i.e. 10.5% precipitation) are caused mainly by lower interception and thus higher precipitation in the beech stand both in winter and summer months. In addition to this, they have considerable water-management importance because generally it is the case of water available for runoff.

Soil moisture represents a separate component in the water budget of the forest. The experimental studies carried out on the balance plots proved that precipitation ± abnormal months markedly affect the water content of soil and thus the water regime of forest stands; on the average of all hydrological years, however, changes in soil moisture in the spruce stand (4.0 mm, i.e. 0.3% precipitation) and in the beech stand (2.0 mm, i.e. 0.2%) were quite insignificant (Table 2).

Snow cover

In winter periods, the regime of hydric efficiency of forest stands is markedly affected by snow cover lying in the Orlické Mts continuously for 4 to 5 months. In the period of snow accumulation, solid precipitation affecting interception processes and the parameters of snow cover are (in addition to climatic effects) the decisive factors contributing to the form and dynamics of runoff during snow melting in spring. Basic data on the snow cover in both comparative stands in the Moravian-Silesian Beskids are given in Table 5.

The number of days with the continuous occurrence of snow ranged from 118 to 141 (on average 132 days in spruce, 135 days in beech). In the experimental spruce stand, the maximum height of snow ranged from 43.6 to 78.7 cm (on average 60.1 cm) and the maximum water value from 120.8 to 242.1 mm (on average 171.0 mm). The parameters of snow cover in the beech stand were characterised by the following data: the maximum height of snow 63.8 to 113.5 cm (on average 82.5 cm), the largest water supply in snow 189.4 to 309.9 mm (on average 235.7 mm).

In the period of snow pack accumulation (November–February), both the height and the water value of snow were always definitely larger in the beech stand

Table 5. Basic data on snow cover in spruce and beech stands in winter periods 1976/1977–1980/1981 (Orlické Mts)

Winter period	Stand	Continuous occurrence of snow cover		Snow cover parameters			Spring thawing of snow		
		from–to	number of days	maximum height	maximum water value	mean density	from–to	number of days	mean intensity of thawing
				cm	mm	g cm^{-3}			mm day^{-1}
1976/1977	spruce	15/11–19/3	124	63.1	170.2	0.266	3/3–19/3	16	9.0
	beech	15/11–24/3	129	81.7	245.0	0.266	3/3–24/3	21	11.7
1977/1978	spruce	14/11–4/4	141	67.2	174.9	0.276	28/3–4/4	7	22.1
	beech	14/11–9/4	146	83.7	222.2	0.284	28/3–9/4	12	24.1
1978/1979	spruce	27/11–15/4	139	47.9	146.8	0.252	9/4–15/4	6	14.4
	beech	27/11–16/4	140	69.7	211.8	0.275	9/4–16/4	7	22.4
1979/1980	spruce	12/12–1/5	141	43.6	120.8	0.257	12/4–1/5	19	5.9
	beech	12/12–1/5	141	63.8	189.4	0.276	12/4–1/5	19	8.4
1980/1981	spruce	1/12–28/3	118	78.7	242.1	0.290	9/3–28/3	19	12.0
	beech	1/12–31/3	121	113.5	309.9	0.291	9/3–31/3	22	14.1
Mean	spruce	26/11–7/4	132	60.1	171.0	0.268	25/3–7/4	13	12.7
	beech	26/11–10/4	135	82.5	235.7	0.278	25/3–10/4	16	16.1

than in the spruce stand. The increasing difference in the parameters between the two compared stands with progressing winter was remarkable. While in the first samplings to measure snow the snow height in the beech stand was by 4–5 cm greater and the snow water value by 4–10 mm higher as compared with the spruce stand, in the period of spring snow melting the difference in snow height amounted already to 20–34 cm and the difference in water supplies in snow was 50–100 mm in favour of the beech stand.

Markedly higher supplies of water in snow (as well as snow height) under the beech stand are the result of the different interception processes of both species in the winter period. After each snow precipitation, the predominant part of snow reached the soil surface in the beech stand free of leaves so that interception losses were minimal. During short-term temporary thaws, which are rather frequent in the region of our mid-mountains and in the period of snow accumulation, snow in the beech stand mostly changed its height, structure and density only, however, the water value did not decrease markedly.

On the other hand, considerable amounts of solid precipitation were intercepted in spruce crowns during every snowfall. When the temperature increased above 0°C, snow from crowns gradually thawed and predominantly in the form of drip went through the snow cover (without being intercepted) into unfrozen soil. Thus, the main cause of the different values of water reserves in snow in both stands was the different ratio of liquid to solid precipitation in spruce and beech in the period of snow accumulation. In winter periods, the difference in precipitation between both types of stands was substantially smaller than the differences in snow water values. Based on the findings it is evident that higher parameters of snow cover in the beech stand do not necessarily mean a more favourable quantitative hydric efficiency.

The onset of intense spring thawing and snow melting is mainly related to climatic conditions and considerable differences can occur between the years (Table 5). Based on 5-year observations, it is possible to determine the average beginning date of the spring thaw in both stands in the Orlické Mts (WSW aspect, alt. 890 m), viz. 25 March. At the same time, it is possible to state that the snow pack thawed in the beech stand always more intensively (on average 16.1 mm day^{-1}) than in the spruce stand (on average 12.7 mm day^{-1}). With respect to the substantially higher water value of snow in the beech stand, however, snow thawed on average within 16 days whereas the mean period of snow melting in the spruce stand was shorter, viz. 13 days only.

Corroboration of findings obtained under the conditions of the Beskids by Zelený (1974) can be considered to be also important from water-management aspects. According to the findings, even extraordinarily intensive snow melting (if it is not accompanied by heavy precipitation) does not result in flood waves. In the Orlické Mts, the mean specific runoff from the thawing snow in the spruce and beech stands ranged usually between 110 and 200l s^{-1} km^{-2}. The highest values were recorded in spring 1978 and 1979, viz. 255 to 280 l s^{-1} km^{-2}.

Conclusions

The 5-year calibration period in mature spruce and beech stands in the Orlické Mts and successive measurements in the stands of the same species, established in 1983 by artificial regeneration to replace the former mature stands after their clear-felling, make it possible to formulate the following basic findings on the water regime of mountain spruce and beech ecosystems:

1. Sufficiently high supplies of atmospheric precipitation (1000–1500 mm $year^{-1}$) ensure the high quantitative water-management efficiency of forest ecosystems in mountain locations of the Czech Republic.
2. The water regime of mature forest ecosystems can be extra improved by horizontal precipitation amounting to 50–150 mm (5–10%) per year at altitudes of over 800 m.
3. With respect to the very low interception of beech, the total consumption of water in mature broadleaved stands is as much as 150 mm lower than that of mature spruce stands. From the quantitative water-management point of view, beech stands are, therefore, markedly more advantageous than spruce stands.
4. Surface runoff with potential subsequent erosion is quite negligible not only in mature stands but (provided that the required logging technologies and procedures are observed) even in large clear-felled areas with slopes exceeding 30%.
5. Due to the higher interception and more favourable runoff balance during winter months, spruce stands are more effective than beech stands from qualitative water-management aspects.

Acknowledgements

The paper was prepared thanks to the financial support from the Grant Agency of the Czech Republic (Project No 526/02/0851 and Research Plan No MSM 434100005 of the Faculty of Forestry and Wood Technology in Brno).

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