Towards a Functional Forest Management for Natural Disaster Mitigation: Aspects on Spatiotemporal Hydrological Properties of Norway Spruce (*Picea abies* (L.) Karst.) and European Beech (*Fagus sylvatica* L.) Forests

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Abstract

Forest cover plays a substantial role as regards run-off processes from catchment areas and thus on the mitigation of natural disasters associated with rainfall events, like peak flows or landslides. Within the framework of natural disaster mitigation, forest management should be aimed at sustaining a maximum performance of this protective function. However, the hydrologic functionality of forests highly varies with forest type, stand structure, silvicultural activities and environmental conditions. Towards the implementation of an optimal forest management scheme, one should clearly identify the potentials and/or limitations of forest functions according to the prevailing site and stand conditions.

This study addresses three crucial hydrological features of forested sites: interception, stemflow and soil water storage. Interception and stemflow, as stand features, govern the entire rainwater input onto the forest floor. The capacity of soil water storage, which can be strongly modified by the stocking stand, determines the spatiotemporal pattern of water discharge from the site.

To identify the influence of forest type and structure on the hydrological response, two contrasting forest stands in sloping terrain were selected near Kreisbach in Lower Austria (15°39′48″E, 48°05′51″N): a one-layer Norway spruce stand and a multi-layer mixed stand dominated by European beech. Meteorological and hydrological data were collected over the growing seasons of 2000 and 2001. Interception and stemflow were calculated for both stands and compared at an event-scale. The temporal resolution of the hydrological processes was also analyzed.

The rainwater interception in the Norway spruce stand was always higher than that in the mixed stand with European beech. For both stands, the percentage of intercepted rain decreased with increasing rainfall intensity and gross precipitation. The difference in rainwater interception between the two stands amounted to 15 % on average, and was mainly due to the absent of stemflow in the spruce stand. Stemflow occurred only along beech stems and reached about 15 % of gross precipitation in the mixed stand during heavy rain events, although the stemflow rate highly varied in events of low intensity and/or low total rain amounts. In some rain events, a remarkable time lag between open field precipitation and the occurrence of stemflow could be observed depending on stem size and tree class. In the mixed stand, more pronounced fluctuations of soil water storage and a deeper reaching soil water depletion could be measured (down to 100 cm depth).

The mixed stand at least compensated for the higher rainwater input onto the forest by a higher degree of spatiotemporal diversity of water infiltration and soil water retention through the utilization of a bigger soil volume. To minimize the amount of rapid run-off, forest management should intend to optimize above- and belowground water storage capacity of the stands, also considering total stand transpiration and thus the soil water status before a rain event. In this sense, a mixed forest is ideal to achieve this goal.

Keywords: multi-layer mixed stands, one-layer coniferous stands, interception, stemflow, soil water storage

Introduction

Forest plays a substantial role on runoff process of catchment area for mitigating natural disasters associated with precipitation events like peak flows or landslides. However, the hydrological properties of forests that directly affect on the run-off process show a broad variation according to stand characteristics, including species composition (Holzmann et al., 1998), stand age and density (Stoneman, 1993; Murakami et al., 2000; Vertessy et al., 2001), and by meteorological conditions, such as rainfall patterns, temperature and wind (Aoki, 2003, Calder et al., 1996).

Within the framework of disaster mitigation, the optimal forest management should be aimed at sustaining maximum performance of its functions for soil and water conservation. In the recent forest policy

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Table 1. Precipitation status during the observation periods (2000 and 2001) and the fraction of hydrological components in the spruce stand and the mixed stand.

Total precipitation in observation period	816 mm (total for the 16 months)
Maximum daily gross precipitation	49 mm (6 August 2000)
Maximum rainfall intensity	20.4 mm/hour (15 May 2001)
Number of rainfall events	95

	Spruce stand		Mixed stand	
Proportional to gross precipitation in each event (%)	Interception	Stemflow	Interception	Stemflow
Mean	41.2 (± 1.3)	-	26.2 (± 1.8)	9.9 (± 0.5)
Standard deviation	±12.5	-	± 17.3	± 5.1
Minimum value	18.2	-	0.5	0.2
Maximum value	78.1	-	72.8	24.3

in Japan, many forest managers have been encouraging conversion of coniferous monocultures to mixed forests with deciduous tree species in protection forests for headwaters conservation, soil loss prevention and landslide control (Asahikawa city, 2006; Nagano prefecture, 2004; The Ministry of Agriculture, Forestry and Fisheries of Japan, 2003). Such mixed form of forests is expected to enhance ideally their functions, as for example canopy interception, flow routing, soil water retention, and soil stabilization. However, such functions performed by mixed forests have often been discussed predominantly in abstract term, without any quantification of its values or drawbacks (Forest agency, 2004). Despite of a number of hydrological studies in various forests over many decades, yet little is known about the hydrological behaviour of such coniferous-deciduous mixed forests on a stand scale (Bosh and Hewlett, 1982; Cape et al., 1991; Forestry and Forest Products Research Institute, 2006; Loshali and Singh, 1992; Takahashi et al., 1997).

In this context, there arises a crucial issue of evaluating their functions in the hydrological process for the robust forest management schemes in disaster mitigation policies. Therefore, this study initially proposes to address the feature of main hydrological processes (interception, stemflow, and the soil water storage) comparing pure coniferous and mixed forest stands at high spatiotemporal resolution.

Method

Study area

The study site is located near Kreisbach in Lower Austria (15°39′48″E, 48°05′451″N). It has the average annual temperature of 8.4 °C and annual precipitation amounts to 850 mm. The precipitation can be characterized as high summer rainfall and the maximum daily rainfall accounted for 107.2 mm (27 July 1966). Precipitation is usually sufficient for spruce and beech, but occasionally summer drought can occur (Schume et al., 2004). The natural plant association in this location is *Asperulo odoratae-Fagetum*. Parent materials for soils are Tertiary and Mesozoic sandstones, marls or mudstones of the Austrian Flyschseries. The soils derived from these materials are high in clay content and exhibit a tendency towards longer periods of water logging. They can be classified as stagnic cambisols.

Two different types of forest stands were selected in the study site: a Norway spruce stand (spruce stand) and a mixed stand dominated by European beech (mixed stand). Each plot has an area of 0.25 ha and the distance between the plot centers was about 150 m. The plots are located on a gentle (20 %) NNW slope at an elevation of 470 m a.s.l. and the relief of the site is smooth. Morphological soil properties, such as thickness of mineral soil layers, texture class or soil structure, showed only very little variation between and within the investigated plots. The humus form in the mixed stand was mull. In the spruce stand moder humus of about 2 cm thickness has developed over time.

The characteristics of the forest stands in the two research plots can be seen from Table 1. The spruce stand has an admixture of less than 4% by volume of beech trees, while other tree species are mainly larch trees. In the mixed stand, the ratio on a volume basis, between beech and spruce is approximately 2 to 1, while other trees are larch, birch and oak. Canopy closures ranged around 90 % and Leaf Area Index were high (Table 1). Trees in the mixed stand were not evenly distributed and showed a clustering by species. The distribution of diameter class at breast height (DBH) varied widely for both stands. In the mixed stand, most of beech trees and spruce trees were 16–20 cm and 24–28 cm DBH class, respectively. 28–32 cm DBH range was mostly dominated the spruce stand.

Table 2. Stand characteristics of the two research plots in the study site (as in 2000): Norway spruce stand and mixed stand dominated by European beech.

	Spruce stand			Mixed stand		
Average Stand age (yr)	56			61		
Stem number (N/ha)	921			988		
Timber volume (m3/ha)	623.7			476.2		
LAI	7.1			7.3		
Dominant height (m)	27 m			27 m		
Number of canopy layer	1			2		
Tree species	Beech	Spruce	Others	Beech	Spruce	Others
Species composition (%)	5.0	88.3	6.7	78.1	18.2	3.7
Timber volume (%)	3.2	89.7	7.1	65.0	30.2	4.8

Instrumentation, data acquisition and analysis

For the evaluation of hydrological properties of the aboveground forest stand, precipitation, canopy throughfall and stemflow were collected for the spruce stand and mixed stand over the growing periods in May-December 2000 and March-October 2001 (total of 16 months) without snowfall.

Tipping bucket rain gauges were set up in both stands and on an adjacent meadow approximately 100 m outside the forest to collect stand precipitation, open field precipitation and rainfall intensity. The selection of individual rainfall events was based on the registration of precipitation in 15 minutes interval. To avoid sampling errors, only events that had rainfall higher than 1 mm and lasted longer than 30 minutes were taken into account. Rainfall events that occurred closely together were differentiated by the period, in which there occurred no stand precipitation at least 4 hours. The period of the cessation was considered long enough for the water settled on the canopy to evaporate (Giacomin and Trucchi, 1992).

Five throughfall collectors were installed in each plot. The throughfall collectors consist of 300-cm long and 10-cm wide stainless steel troughs with a total area of 1.5 m^2. They were laid out representatively at 1 m above the litter to avoid ground splash. Collected throughfall was led off to each large-capacity gauge and measured regularly.

Stemflow was measured only in the mixed stand, since no stemflow observed in the spruce stand. Totally six European beech stems were selected randomly to represent entire diameter class. Stemflow was collected using a neoprene rubber collars, which was coiled helically 1.5 times around the bole at breast height, and sealed to the bark using neoprene sealant.

Interception was calculated by the subtraction of open field precipitation, stemflow and throughfall in each individual rainfall event.

To obtain the vertical distribution of volumetric water content (VWC) in forest soil, waveguides (set of 30 cm and 60 cm long) were installed horizontally in the forest soil along the uphill walls of excavated pits at the depth of 10, 20, 40, 55, 75 and 100 cm. After installation, the soil pits were filled up with the excavated soil material in stratified order. VWC was measured with a TDR system every hour at one location per plot.

In addition, sensors for measuring air temperature, wind speed and atmospheric humidity were mounted on a mast 4 m above canopy. Climatic parameters were measured every 15 seconds and the 15 minute-averages were continuously recorded.

Results and Discussion

Rainfall pattern and its influences on the interception and stemflow in two forest stands

Table 2 summarizes the proportion of aboveground hydrological components to the gross precipitation in individual rainfall events over two growing periods. The mean interception in the spruce stand was significantly higher than that in the mixed stand, and the difference between the mean values comprised 15 % of the gross precipitation (Table 3). The spruce stand intercepted about 40 % of gross precipitation in events. Interception, however, varied widely across the rainfall events in both stands: from 18.2 to 78.1 % in the spruce stand and from 0.5 to 72.8 % in the mixed stand (Table 2).

Fig. 1 shows that the variation of interception in both stands according to the gross precipitation, the maximum rainfall intensity and the duration of individual rainfall event. Fig. 1a presents that the interception in both stands decreased gradually with increasing gross precipitation. There are several evidences that support a negative semi-logarithmic relationship between interception and gross precipitation (Hager, 1988; Lin, 1968;

Table 3. Summary table for the mean value comparison of interception rates in the spruce stand and the mixed stand.

Paired t - test

Data: Interception for the spruce and the mixed stand (%)	
DF	9 4
F	0.524 > p-value = 0.002
t	21.582 > p-value = 2.2e-16
Mean of the differences (%)	14.983 (± 1.378)

Table 4. Summary table of regression for interception rate and gross precipitation in rainfall events.

y = a – b · log (x)

y: Interception (%), x: Gross precipitation in event (mm)

	spruce stand	Mixed stand
a	54.39 (±2.34)	45.96 (± 3.04)
b	7.55 (±1.20)	11.27 (± 1.56)
r-square	0.30	0.36
Res.Std.Error	10.50	13.63
DF	93	93
codes	***	***

sign. Codes: 0 ***, 0.001 **, 0.05 .

Viville et al., 1993). Although the regression curves did not fit very well in our observation, the negative correlation between interception and gross precipitation was significant in both stands (Table 4). The result indicates that the interception in the spruce stand was significantly greater at any rainfall events than that in the mixed stand. Furthermore, the interception in the mixed stand eventually decreased to zero at around 50 mm of gross precipitation, while the spruce stand retained still about 20 % of rainwater even at large events (∼70 mm). Relatively high proportion of interception was observed only in small rainfall events for both stands (gross precipitation < 10 mm). In some rainfall events, both stands captured about 70–80 % of rainwater. The differences between two stands were remarkably large at small rainfall events, up to 30 % in some individual events.

The coefficients of determination on the regression analysis between interception rates and the maximum rainfall intensity as well as the duration of rainfall events were very low in both stands. Therefore, the trends of interception on both rainfall variables were calculated using a locally weighted regression method (Loess method with nearest neighbor algorithm). A decrease in interception was identified with respect to the maximum rainfall intensity and the duration of events (Fig. 1b and c). Still the spruce stand had higher interception rates with both variables than that in the mixed stand. Interception in the mixed stand declined to around zero, in the spruce stand yet about 20 % of gross precipitation at the event under 20 mm/h and 30 hours duration, respectively.

The mean stemflow accounted for 9.9 % in proportion to the gross precipitation during two growing periods (Table 2). Stemflow in European beech forests lies around 10 % on average (Çepel, 1967; Hörmann et al., 1996; Tuzinsky, 2000). Stemflow showed a broad range of variation, from 0.2 to 24.3 % in small rainfall events (Fig. 2). The local weighted regression was also adapted to detect the trends of stemflow according to the rainfall patterns. Fig. 2a shows that the change in stemflow according to the gross precipitation together with the magnitude of the maximum rainfall intensity in each event. Stemflow increased slowly until the gross precipitation reaches 30 mm, and then converged at around 15 % in proportion to gross precipitation. However, no clear influence due to rainfall intensity was identified in this process. Stemflow also increased with the maximum rainfall intensity and the duration of rainfall event (Fig. 2b and c). Stemflow reached around 10–15 % of gross precipitation, as the maximum rainfall intensity also increased. Stemflow was slightly increased by increasing rainfall duration (15–20 %).

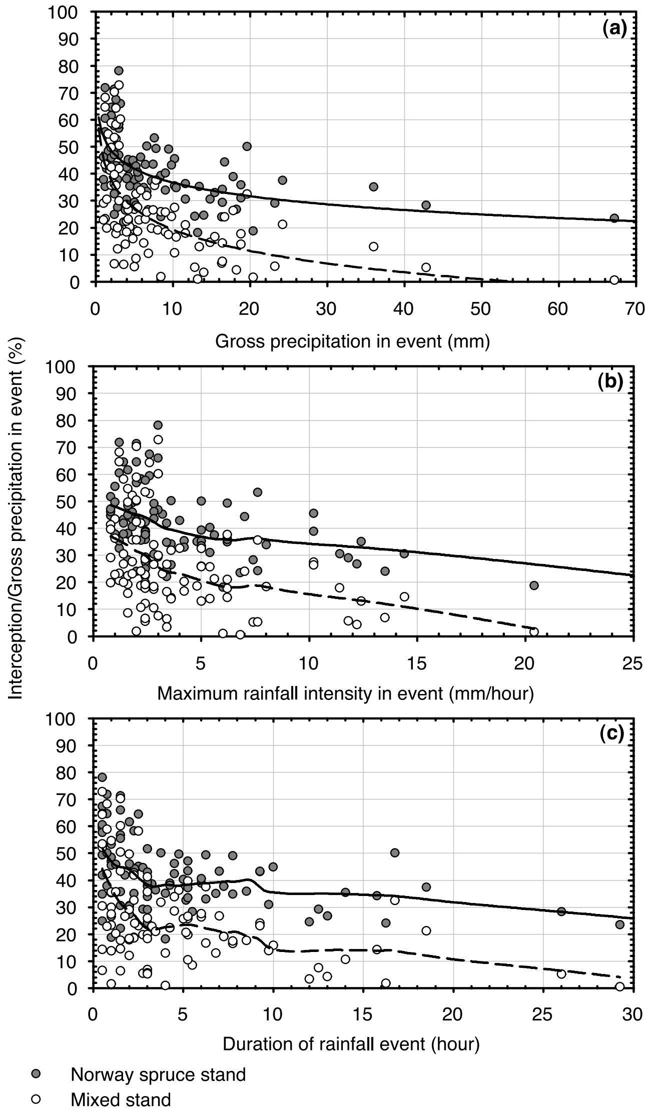

Fig. 1. Comparison of interception rates in the spruce stand and the mixed stand and their variation according to (a) gross precipitation, (b) maximum rainfall intensity, and (c) rainfall duration at individual rainfall events (n=95).

Temporal processes of aboveground rainfall partitioning and influential factors

The rainfall pattern and the condition of forest stand, both influence directly the course of rainwater partitioning. The temporal resolution of rainwater detention as well as partitioning by interception and stemflow were analyzed in the mixed stand at event-scale. Two contrasting rainfall events were selected to evaluate these dynamics: the rainfall events under relatively high (heavy event) and low rainfall intensity (light event) from the observation period. Fig. 3 illustrates the time courses of cumulative interception and stemflow in depth as well as in proportion to gross precipitation for both rainfall events.

Fig. 3a depicts that interception rose quickly after the start of the high intensity rainfall event (12.2 mm/h). Then the amount of retained water reached the maximum of about 3 mm. Interception decreased gradually as the rainfall exceeded the maximum storage capacity of the aboveground tree surface (3 hours after the rain start). Looking into the fraction of rainfall partitioning, the interception rate dropped rapidly from 100 to 20 % at the beginning of the event. In contrast, stemflow was increasing during the rainfall event. After about 7 hours from the rainfall start, stemflow slightly exceeded interception and the both remained constant at about 10 % of gross precipitation. The decline in cumulative interception (in depth) can be interpreted in the following ways: the rain weakened once after 2 hours from the start of the event and the rainwater input to the forest stand substantially decreased. The reallocation of detained water on the canopy (throughfall) was accelerated by increasing wind speed (from 1 to 4.5 m/s) after a short break in precipitation, since stemflow was still constant at this point.

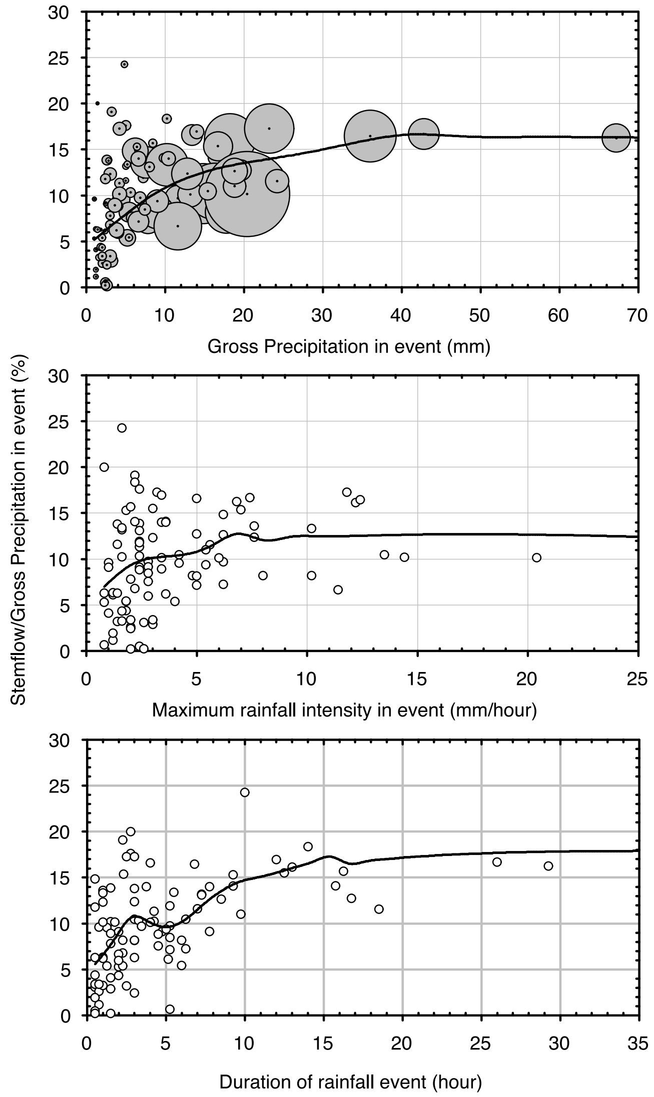

Fig. 2. Variation of stemflow (%) in individual rainfall events according to (a) gross precipitation with magnitude of maximum rainfall intensity (grey circle), (b) maximum rainfall intensity, and (c) rainfall duration for the mixed stand (n=95).

In the light rainfall event shown in Fig. 3b, interception and stemflow increased progressively and reached the maximum amount at about 12 hours after the rainfall start. However, the decline in interception did not appear through the event. In addition, at the beginning of rainfall, rainwater was fully intercepted until about 1 hour. The fraction of interception decreased gradually, and eventually reached about 20 % of gross rainfall. Remarkably, there was a time lag in the starting of stemflow. It was about 2 hours from the rainfall start, while at the heavy rainfall event stemflow started shortly after the beginning of rainfall (about 15 minutes).

Fig. 4 shows the temporal process of rainwater movement through stemflow at each selected representative beech tree for the heavy rainfall event and light rainfall event, respectively. Fig. 4a illustrates that stemflow of all trees occurred immediately after the intense rain. Stemflow increased drastically at the large trees (22.2, 29.8 and 36.6 cm DBH), while the other smaller trees rose gradually despite of the high rainfall intensity. In contrast, a time lag in stemflow was observed in the light rainfall event (Fig. 4b). Stemflow appeared first at the large stems (36.6 cm and 29.8 cm DBH) at about 2 hours after the beginning of the rainfall. The time lag of the occurrence for other small stems was about 3 hours.

Stemflow generally starts from small trees, since the wetting along the flow path of large trees takes longer time due to the high storage capacity (Delfs, 1967). However, the larger trees came into the process initially prior to the smaller trees in many events. In multi-layer forest stands, the vertical profile of trees (tree class) will influence strongly to the sequence of stemflow. In the study plot, it can be inferred that the

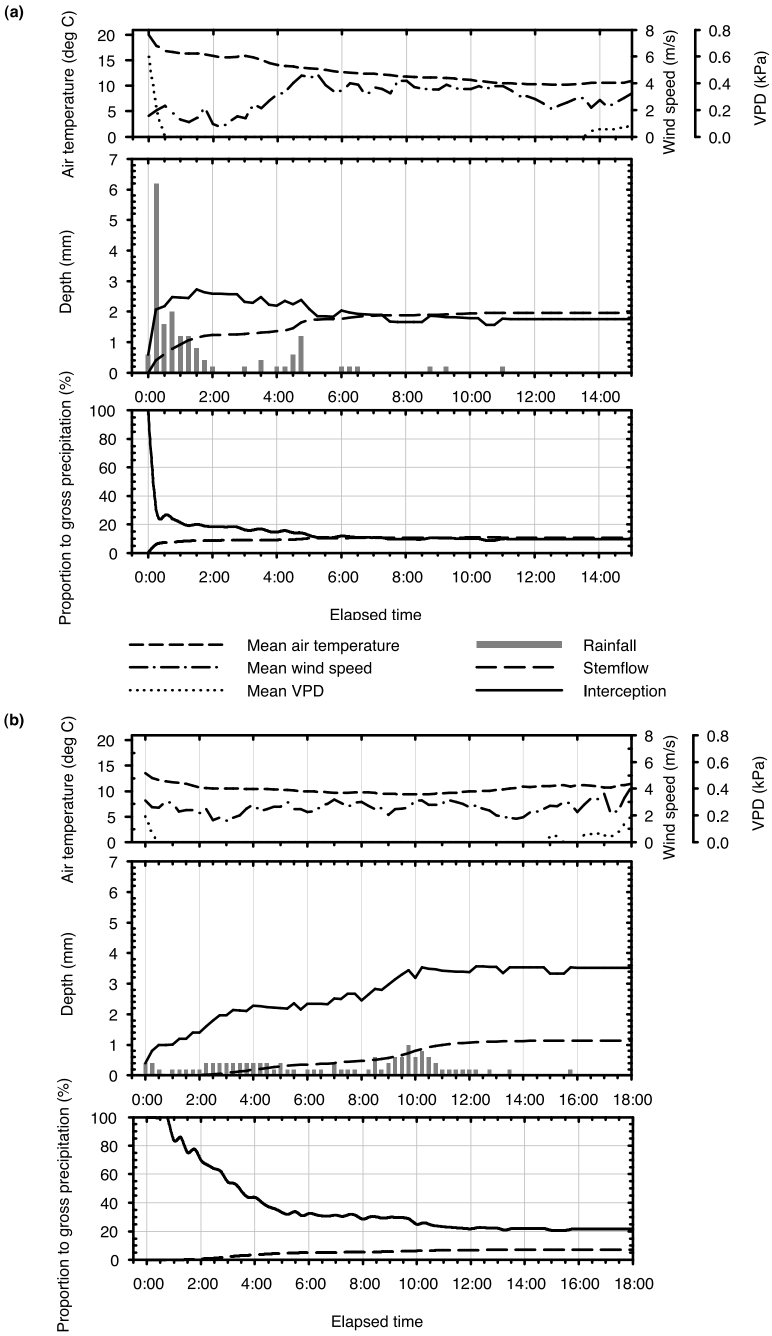

Fig. 3. ime course of cumulative interception and stemflow (in depth and fraction) and meteorological parameters in the mixed stand during (a) heavy rainfall event (18.2 mm, 12.2 mm/h, 13 h; 6. June 2000) and (b) light rainfall event (16.4 mm, 3.6 mm/h 15.75 h; 24. June 2000).

large trees dominated in the top canopy layer at first received rainwater, while the lower inferior trees were suppressed until the free throughfall or canopy drip from the upper trees start.

The trees with greater DBH indicated not only higher increment but also greater capacity in rainwater transport than those of smaller ones. The volume of rainwater that can be generated to stemflow depends on the stem size (Aoki, 2003). In addition, the architecture of individual trees (crown form, branch inclination angle) or canopy overlapping of neighboring trees may also affect the transport capacity of stemflow, especially for multi-layer stands (Crockford and Richardson, 2000; Ford and Deans, 1978; Herwitz, 1987; Ovington, 1954).

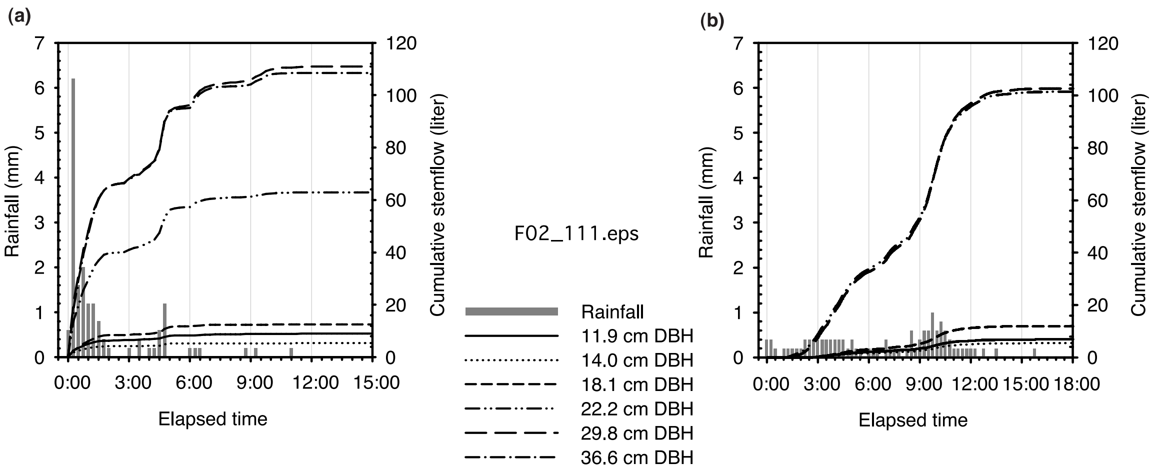

Fig. 4. Temporal resolution of precipitation and stemflow at selected European beech stems in the mixed stand during (a) heavy rainfall event on 6 June 2000 (18.2 mm, 12.2 mm/h, 13 h: n=6) and (b) light rainfall event on 24 June 2000 (16.4 mm, 3.6 mm/h 15.75 h: n=5).

Spatiotemporal characteristics of soil water storage in both stands

Fig. 5 shows the comparison of spatiotemporal patterns in volumetric water content (VWC) over soil depth between the spruce stand and mixed stand during the growing period in 2001. It shows that in spring deeper soil horizons were generally wetter under the mixed stand than under spruce. Changes of VWC, as for example from rewetting under heavier precipitation, were more pronounced in the mixed stand, while the course of wetting and drying was more even in the spruce stand. It also shows that from end of May (late spring) soil water was depleted gradually in both stands despite of quite a number of heavier rainfall events. This depletion continued until mid of September. It was more emphasized in the mixed stand and reached further down into the soil profile. The 27 %-VWC isoline, for instance, extended in 60 cm depth from the beginning of July until mid September, while in the spruce stand this isoline lay almost up to 30 cm in depth. In the same study site, Schmid (2002) found 80 % of beech fine roots (< 2 mm) were located between 20 and 60 cm soil depth, while rooting of spruce was restricted to the uppermost 30 cm. No fine roots of spruce occurred below 60 cm. Fine roots of beech were more uniformly distributed over depth, and a small percentage reached the maximum investigation depth of 85 cm in the mixed stand. Having access to a larger available soil volume, beech was able to maintain higher transpiration rates (Jost et al. 2004). As a result, the water depletion of soil was more intense in mixed stands but it has more absorption capacity of soil water from precipitation.

Conclusions

The Norway spruce stand has the advantage in high rainwater interception. In contrast, the mixed stand with European beech particularly enhances the degree of spatiotemporal diversity of rainwater input. Stemflow plays a substantial role in the process of rainwater allocation, although the performance strongly depends on the property of rainfall events and stand characteristics such as stem size and tree class. Moreover, the mixed stand has great soil water retention through bigger soil storage volumes. To minimize the high amount of rapid run-off, such aboveground and belowground water storage capacities of forest stands should be optimized. The consideration of spatiotemporal diversity in rainwater input onto the soil surface and storing process in the soil can secure the performance of water regime function of forests.

In addition, the result of Schmid and Kazda (2002) at the same study site shows the vertical distribution of large roots (> 20 cm) differs between the spruce stand and the mixed stand. In a same soil condition, large roots were distributed down to 80 cm soil depth in the mixed stand but in the spruce stand they were limited to the upper 40 cm. Taking into account of improving vertical roots development, managing mixed forests will also enhance the slope stabilization function.

In this sense, the management of mixed forests should be one of the principal schemes for foresters in the framework of natural disaster mitigation.

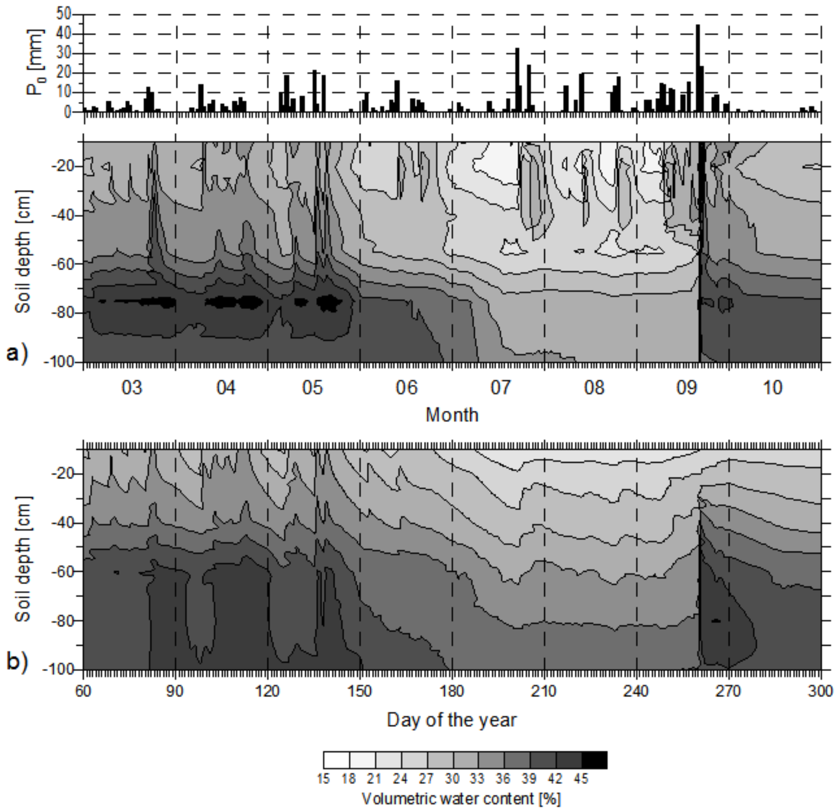

Fig. 5. Daily precipitation (P0) records and seasonal development of volumetric soil water content (VWC) over depth in (a) mixed stand dominated by European beech and (b) Norway spruce stand throughout the growing period (from March to October in 2001).

References

Aoki K. (2003) *Stammablauf und Interzeption in Zwei Waldbeständen in Abhängigkeit von meteorologischen Variablen.* Diploma thesis. University of Agricultural Sciences Vienna. Vienna, Austria. P.98.

Asahikawa city, (2006) *Forest management plan for 2004–2014*, revised version, forest policy subsection, Agriculture-forest service section, Hokkaido, p.28, in Japanese.

Bosch, J.M. and Hewlett, J.D. (1982) A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *J. Hydrol.* 55, 3–23.

Calder, I.R., Hall, R.L., Rosier, P.T.W., Bastable, H.G. and Prasanna, K.T. (1996) Dependence of rainfall interception on drop size: 2. experimental determination of the wetting functions and two-layer stochastic model parameters for five tropical tree species. *J. Hydrol.* 185, 379–388.

Cape, J.N., Brown, A.H.F., Robertson, S.M.C., Howson, G. and Paterson, I.S. (1991) Interspecies comparisons of throughfall and stemflow at three sites in northern Britain. *Forest Ecol. Manage.* 46, 165–177.

Çepel., N. (1967) Interzeption in einem Buchen-, einem Eichen- und einem Kiefernbestand del Belgrader Waldes bei Istanbul. *Forstwirtschaftl. Zentralblatt*, 301–314.

Crockford, R.H. and Richardson, D.P. (2000) Partitioning of rainfall into throughfall, stemflow and interception: effect of forest type, ground cover and climate. *Hydrol. Process.* 14, 2903–2920.

Delfs, J. (1967) Interception and stemflow in stands of Norway spruce and beech in West Germany. In: Sopper, W.E., Lull, H.W. (Eds.), *International Symposium on Forest Hydrology*, Pergamon Press, New York, 179–185.

Ford, E.D. and Deans, J.D. (1978) The effects of canopy structure on stemflow, Throughfall and interception loss in a young Sitka spruce plantation. *J. Appl. Ecol.* 15, 905–917.

Forest agency, (2004) *Annual report on trends of forest and forestry*, fiscal year 2003. Forestry Agency, The Ministry of Agriculture, Forestry and Fisheries of Japan, Japan forestry association, p.274, in Japanese.

Giacomin, A. and Trucchi, P. (1992) Rainfall interception in a beech coppice (Acquerino, Italy). *J. Hydrol.* 137, 141–147.

Hager, H. (1988) *Stammzahlreduktion: Die Auswirkungen auf Wasser-, Energie- und Nährstoffhaushalt von*

Fichtenjungwüchsen. Forstliche Schriftenreihe Band 1. Österreichsche Gesellschaft für Waldökosystemforschung und experimentelle Baumforschung, Universität für Bodenkultur, Wien, p.189.

Herwitz, S.R. (1987) Raindrop impact and water flow on the vegetative surfaces of trees and the effects on stemflow and throughfall generation. *Earth Surface Processes and Landforms* 12, 425–432

Hörmann, G., Branding, A., Clemen, T., Herbst, M., Hinrichs, A. and Thamm, F. (1996) Calculation and simulation of wind controlled canopy interception of a beech forest in northern Germany. *Agric. For. Meteorol.* 179, 131–148.

Holzmann, H., Hager, H., Pichler, M. and Sereinig, N. (1998) Assessment of hill slope runoff processes on a local scale emphasising forest vegetation effects. In: Tappeiner, U., Ruffini, F.V., Fumai, M. (Eds.), *Hydrology, water resources and ecology of mountain areas.* Proceedings of Head Water conference in Meran, Italy. European Academy Bozen/Bolzano, p.171–175.

Jost, G., Schume, H. and Hager, H. (2004) Factors controlling soil water-recharge in a mixed European beech (Fagus sylvatica L.) — Norway spruce [Picea abies (L.) Karst.] stand. *Eur J Forest Res.* 123, 93–104.

Lin, P. C. (1968) *Einflüsse verschiedener Pflanzenbestände auf den Wasserhaushalt in einem Einzugsgebiet.* Dissertation, Ludwig Maximilians Universität, München.

Loshali, C. and Singh, R.P. (1992) Partitioning of rainfall by three Central Himalayan forests. Forest Ecol. Manage. 53, 99–105.

Murakami, S., Tsuboyama, Y., Shimizu, T., Fujieda, M. and Noguchi, S. (2000) Variation of evapotranspiration with stand age and climate in a small Japanese forested catchment. *J. Hydrol.* 227, 114–127.

Nagano prefecture, (2004) *Forest-water project*, 1st report, Nagano prefecture, forest conservation section, p.73 , in Japanese.

Ovington, J.D. (1954) A comparison of rainfall in different woodlands. *Forestry* 27, 39–53

Schmid, I. (2002) The influence of soil type and interspecific competition on the fine root system of Norway spruce and European beech. *Basic Appl. Ecol.* 3 (4), 339–346

Schmid, I. and Kazda, M. (2002) Root distribution of Norway spruce in monospecific and in mixed stands on different soils. *Forest Ecol. Manage.* 159, 37–47.

Schume, H., Jost, G. and Hager, H. (2004) Soil water depletion and recharge patterns in mixed and pure forest stands of European beech and Norway spruce. *J. Hydrol.* 289, 258–274.

Stoneman, G.L. (1993) Hydrological response to thinning a small jarrah (Eucalyptus marginata) forest catchment. *J. Hydrol.* 150, 393–407.

Takahashi, M., Sakamoto, T., Terashima, T., Nakai, Y. and Matsuura, Y. (1997) Seasonal changes in the concentrations of suspended sediment, organic carbon, and inorganic carbon of stream water from a small catchment of temperate mixed conifer-hardwood forest, Hokkaido, northern Japan. *Gordon conference on Hydrobiogeochemistry of Forested Watersheds*, Colby-Sawyer College, NH, USA., p.10.

Teklehaimanot, Z., Jarvis, P.G. and Ledger, D.C. (1991) Rainfall interception and boundary layer conductance in relation to tree spacing. *J. Hydrol.* 123, 261–278.

The Ministry of Agriculture, Forestry and Fisheries of Japan (2003) *The basic plan for the national forest management.* The Ministry of Agriculture, Forestry and Fisheries of Japan, p.13, In Japanese.

Tuzinsky, L. (2000) Spruce and beech forest stands water balance. *Ecology-Bratisl.* **19**(2), 198–210.

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

Viville, D., Biron, P., Granier, A., Dambrine, E. and Probst, A. (1993) Interception in a mountainous declining spruce stand in the Strengbach catchment (Vosges, France). *J. Hydrol.* 144, 273–282.